Collateral Advantage: Exchange Rates, Capital Flows, and Global Cycles*

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Abstract

We construct a two-country New Keynesian model in which US government debt has an advantage as a superior collateral asset on the balance sheets of banks. The model can account for the observed exchange rate and external position behavior of the US. In our model, the US enjoys an "exorbitant privilege" as its government bonds are desired by banks both in the US and abroad as superior collateral. In times of global stress, the dollar appreciates since the demand for high-quality collateral drives up the "convenience yield" earned by US government bonds . There is "retrenchment" - each country reduces its holdings of foreign assets - a critical determinant of which is the endogenous response of prices and returns. In addition, the model displays a US real exchange rate appreciation despite that domestic absorption in the US falls relative to the rest of the world during a global downturn, thus addressing the "reserve currency paradox" highlighted by Maggiori (2017).

JEL Classification Codes: F3, F4, G1

Key words: Exchange rates, financial frictions, liquidity, convenience yield, dollar specialness

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1 Introduction

During the global financial crisis of 2007-2009, the US Federal Reserve cut interest rates more quickly and sharply than central banks of most other major economies, yet the US dollar appreciated. Analysts refer to a "flight to quality", highlighting the high demand for liquid and safe assets in influencing exchange rates. The appreciation of the dollar has been associated with large reversal (or retrenchment) of capital flows, and with the "exorbitant duty" of the US currency – meaning that foreign investors are rewarded during times of global stress by an increase in the value of their US assets. This amounts to a wealth transfer from the US to the rest of the world. This exorbitant duty is the complement of the "exorbitant privilege" the US enjoys during quiescent times, as the average return on US investments abroad exceeds that of foreign investments in the US.[1]

Such behavior of the dollar implies that the dollar is a hedge during times of global downturn, so it seems plausible that the low rate of return on US assets is attributable at least in part to their value as insurance. But this leaves open the question of why the dollar appreciates during downturns. Gourinchas and Rey (2022) provide a model in which global demand for dollar assets as insurance increases as the potential for a global crisis increases. Bianchi et al. (2021), on the other hand, attributes the appreciation to liquidity demand arising from financial intermediaries. A disproportionate amount of volatile, short-term funding globally is in dollars, and as funding becomes more uncertain, the demand by intermediaries for liquid dollar assets increases, thus appreciating the dollar. Kekre and Lenel (2021) and Jiang et al. (2020) construct models in which the dollar appreciates because it earns a higher "convenience yield" during times of global stress. The convenience yield arises in those frameworks because agents directly derive utility from dollar assets, though this is meant to be an expedient way to capture the various factors such as liquidity services that are provided by dollar assets.[2]

In this paper, we propose a framework that can explain these disparate features of the global financial crisis. We construct a two-country New Keynesian model in which US government debt is superior collateral on the balance sheets of financial intermediaries. In other words, for a balanced sheet-constrained financial intermediary, it is less costly to hold US Treasury debt than safe assets of other countries. The higher pledgeability of US Treasury debt creates a liquidity or "convenience" demand for the debt. When there is financial stress, the balance sheet constraint is a bigger concern, which endogenosly generates a high "convenience yield" for US Treasury debt. This leads all financial intermediaries to shift demand towards US Treasury debt, causing a dollar appreciation. The appreciation of foreign bank's US assets results in an effective wealth transfer

[1] Gourinchas and Rey (2007a,b, 2022) and Eichengreen (2011) originate this idea, provide empirical evidence to support it, and build models to account for it.

[2] See also Engel (2016) and Engel and Wu (2023) for New Keynesian models in which the convenience yield comes about because bonds are in the utility function.

such that the US financial intermediaries demand more of the liquid assets than the foreign banks. This results in an endogenous capital flow retrenchment: the US intermediaries end up holding more US assets and the foreign intermediatures hold more foreign assets. The model also features a persistent deviation from uncovered interest parity (UIP) due to a time varying convenience yield, and simultaneously a long run "exorbitant privilege", as US assets pay a lower interest rate than those of the rest of the world.

Our model is a two-country, New Keynesian DSGE model with a financial sector as in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). In each country, households consume, provide labor services, and save by putting deposits in banks located in their own country. Firms in each country produce output using labor and capital. Banks in each country rent capital to firms in both countries, supply deposits to households, and hold government bonds from both countries. Governments issue debt and make transfers to households. Monetary policy in each country is modeled as a simple inflation-targeting rule.

Markets or regulators constrain the banks from acquiring too large a balance sheet, because financial intermediaries (which we shall call "banks") have private information about the value of their assets that is not observed by private agents or financial regulators. In order to prevent excessive risk taking, the leverage of banks is constrained. However, there is less private information about the value of government debt, and especially US government debt that is widely traded globally in very deep markets. In our set-up, US and foreign banks are less constrained in their holdings of government debt, and US Treasury debt has a "comparative advantage" in the sense that the relative constraint on this debt is lower globally than on foreign government debt. The fact that the value of US Treasury debt is easily assessed in global markets is one sense in which these assets are very liquid. We draw a connection between liquidity and "safety". As Gorton (2017) states, "A safe asset is an asset that is (almost always) valued at face value without expensive and prolonged analysis. By design, there is no benefit to producing (private) information about its value, and this is common knowledge" This is precisely the motivation for our modeling of the special role of US Treasury assets in bank balance sheets.

The banks face constraints requiring that a weighted average of the value of their assets must be less than some multiple of the equity value of the bank. However, the weights on the government bonds are lower than the weight on capital, implying that banks are less constrained in their holdings of government bonds. Importantly, though, banks are less constrained in their holdings of US government bonds, which are considered to be better collateral. Globally, therefore, US debt is especially safe/liquid.

Even abstracting from the insurance premium (as in Gourinchas and Rey (2022)) that US Treasury debt might earn, the model exhibits an exorbitant privilege enjoyed by the US. During normal times, US debt pays a low rate of monetary return because it constrains banks' balance sheets less than other assets. In fact, the model is capable of accounting for the fact that while the US is a net international debtor, its net investment income is positive, a noted feature of the US balance of payments.

Moreover, the model explains the appreciation of the dollar during times of global downturn as an increase in demand by banks, both in the US and abroad, for dollar Treasury debt. This appreciation is coincident with an increase in the convenience yield on US government debt, measured as a deviation from uncovered interest rate parity. The global downturn may be caused either by a financial crisis (modeled here as a uniform tightening of borrowing constraints) hitting all countries equally, or a global negative total factor productivity shock.

However, our model demonstrates an important feature of equilibrium adjustment in the global economy. While the foreign bank, *ceteris paribus*, demands more of the US bond, we find in our baseline calibration that both the value of US bonds held by the foreign bank and their share in its portfolio of assets decline. This finding highlights the importance of understanding the equilibrating process when demand for assets change. Here, there are two important features that lead the foreign bank to shed some of its holdings of US bonds. First, because of the dollar real appreciation, the foreign currency value of the bank's holdings of US bonds increases even without a change in the quantity that it holds. Second, the increase in US demand for US bonds is stronger, as it has a greater incentive to shift out of non-governmental assets. As we will explain, the advantage of US government bonds relative to equity capital is greater than the equivalent for foreign bonds. The global increase in demand drives down the relative rate of return on these US bonds (that is, there is an increase in the convenience yield), which ultimately leads foreign banks to decrease their holdings of US bonds and increase their holdings of foreign bonds. In other words, there is *retrenchment*: banks both in the US and abroad shed assets of the other country (bonds and equities) during times of global stress, a prediction which is consistent with the empirical findings of Milesi-Ferretti and Tille (2011), Forbes and Warnock (2012) and, with a particular focus on banks, Wang (2018).[3]

The "reserve currency paradox" of Maggiori (2017) notes that during these times in which the dollar appreciates, the net international investment position of the US deteriorates as the value of US holdings of foreign assets falls relative to the value of foreign holdings of US assets. The paradox is that if the real value of the dollar is determined through home bias in preferences (or through the presence of non-traded goods) by a rise in the price of goods favored by US households, then a real appreciation of the dollar should be associated with an increase in relative demand by US households. It is difficult to reconcile an increase in demand by US households with a fall in

[3] Tabova and Warnock (2021) in fact show that foreign holdings of US Treasury bonds fell during the Global Financial Crisis, though their focus is on long-term bonds and much of that change in portfolios was driven by central bank holdings.

their wealth. This paradox is resolved in our model because nominal goods prices are sticky in the currency of consumers (local-currency pricing, or LCP.) A real appreciation is not immediately associated with an increase in the relative price of US goods.

We also consider the effects of monetary shocks in this framework. As the work of Rey (2015), Miranda-Agrippino and Rey (2020), and others have emphasized, there are repercussions from US monetary shocks on the rest of the world that work through financial channels, and not just through the traditional channels of import demand. We consider the effects of an equal monetary contraction in the US and the rest of the world. The insight from this exercise is that even when monetary policy changes are identical across countries, there is an asymmetric effect on the dollar exchange rate. If the US and other countries were to follow uniform monetary contractions (for example, in response to the inflationary shock in 2022), the dollar would nonetheless appreciate. The contraction lowers aggregate demand, and tightens balance sheet constraints on banks, precipitating a global increase in demand for dollar bonds and an appreciation.

Because the liquid dollar assets earn a convenience yield as well as a monetary return, the central bank effectively has two instruments that can affect macroeconomic outcomes. Its monetary policy - the rule for setting interest rates in response to inflation - works as in standard models, but the central bank can also affect the supply of liquid and convenient assets. As Rogoff (2017) has argued, increasing reserves in the banking system is tantamount to greater issuance of liquid assets by the government. When reserves earn interest, there is little difference between increasing the supply of liquid short-term bonds and increasing reserves. We demonstrate how different menus of monetary policy and unconventional policies (in the form of swapping liquid bonds for less liquid assets), and, somewhat similarly, sterilized intervention, can affect the mix of inflation, currency value and other aggregate variables. For example, if the monetary contraction in the US in 2022 were not accompanied by quantitative tightening, the dollar appreciation over that period may have been significantly reduced.

There are two key differences between our model and models that posit an exogenous increase in US bond demand, for example coming from a demand shock from noise traders as in Itskhoki and Mukhin (2021a,b), or an exogenous switch in demand of bond investors, as in Kekre and Lenel (2021) or Jiang et al. (2020, 2021b). In our model, we posit a uniform global tightening of financial constraints. This has the effect of endogenously increasing the relative demand for US bonds and increasing the convenience yield during times of global financial strain. Second, the financial constraints matter for the response of the global economy. For example, the tightening of financial constraints leads to a reduction in investment directly, but there is also a magnifying effect as financial intermediaries rebalance their portfolios away from productive capital investments toward liquid bonds backed by governments during times of financial stress. Thus, global financial shocks in our model does lead to a deviation from uncovered interest parity, which Miyamoto et al. (2022) find is the dominant driver of dollar exchange rates. Additionally, as noted above, our model features endogenous retrenchment as the financial intermediaries' reallocation of assets in their portfolios induces a decline in foreign asset positions during times of financial pressure even as demand for liquid dollar assets increases, due to the influence of equilibrium changes in expected returns, asset prices, and the exchange rate.

Related Literature

Several recent papers have found a relationship between "convenience yields" and either exchange rates or deviations from uncovered interest rate parity. These include Jiang et al. (2021a), Jiang et al. (2021b), Krishnamurthy and Lustig (2019), Engel and Wu (2023), Kekre and Lenel (2021), Valchev (2020), and Bianchi et al. (2021). These papers provide evidence that deviations from UIP may be attributable in part to liquidity or convenience yields, and that this return to liquidity also influences the level of the exchange rate. Much of the literature has noted especially the nexus between convenience yields on US government bonds and the level of the dollar exchange rate as well as deviations from UIP for the dollar. These models follow earlier literature that takes the deviation from UIP due to the convenience yield either as exogenous, or because some assets are in the utility function, or from exogenously given bond demand functions.[4] An exception is Bianchi et al. (2021), which models the endogenous demand for assets from financial intermediaries during times of global stress, with emphasis on the liquidity return of dollar short-term assets. That model, however, is too stylized to take to a realistic quantitative open-economy macro setting.

The "exorbitant privilege" of the United States - that it earns a greater rate of return on its foreign investments than foreigners earn on investments in the US - in conjunction with the persistent US trade balance and current account deficits has been intensively investigated. Gourinchas and Rey (2007b), Gourinchas and Rey (2007a) and Bertaut et al. (2023) note the importance of these excess returns in the global financial adjustment process. Mendoza et al. (2009), Caballero et al. (2008). Caballero et al. (2016), and Sauzet (2023) build models to account for this global pattern of portfolio returns. A noted feature of this "exorbitant privilege" has been that the US net international investment position, up to the late 2000's, was significantly less than the cumulated level

[4] Earlier papers that model the convenience yield as arising from assets in the utility function include Krishnamurthy and Vissing-Jorgensen (2012), Nagel (2016), and, in an international model, Engel (2016). A prominent recent example of a model with an exogenous UIP shock is Itskhoki and Mukhin (2021a).) Greenwood et al. (2020) and Gourinchas et al. (2022) specify international portfolio choice models iin which a "preferred habitat" as well as risk and return play a role in asset demand. Du et al. (2018a) provide measures of the convenience yield on US bonds relative to government bonds of other countries. Brunnermeier et al. (2022) study a framework in which a safe debt provides service flow because it provides insurance for idiosyncratic risk. Coppola et al. (2023) study a model in which dollar-denominated debt is liquid and dominant. Garleanu and Pedersen (2011) study the asset pricing implications of a model in which assets have different margin requirements. Georgiadis et al. (2023) provides an interesting related framework to understand the global financial cycle also assuming differential financial constraints on asset types, but imposing more structural assumptions than in our paper. Kim (2023) studies the implication of quantitative easing and foreign exchange intervention using a money search model with differential financial constraints.

of current account deficits since the early 1990's. However, recent work by Atkeson et al. (2022) has called attention to a reversal in this situation since the global financial crisis due to the superior performance of US equities relative to those in the rest of the world. It is not obvious however if this reversal has affected the convenience yield on US government bonds relative to those of other major sovereign borrowers.

The role of global financial intermediation is the focus of much contemporary research into exchange rates and capital flows. Notable contributions include Maggiori (2017), Gabaix and Maggiori (2015), Itskhoki and Mukhin (2021a), and Gopinath and Stein (2021).[5]

Some other recent studies have provided potential explanations for how dollar bonds can earn on average a lower return than foreign bonds, and how the dollar can appreciate during global downturns, and yet provide resolutions to the reserve currency paradox. In Maggiori (2017), foreign banks face balance sheet constraints, while US banks are unconstrained. This effectively makes foreigners more risk averse than investors in the US.[6] In equilibrium, the US borrows from abroad and invests in equities, while the foreign country buys US debt which acts as insurance during global downturns. However, since the real exchange rate is determined by the relative price of goods produced in the US compared to those in the foreign country due to home bias in preferences, there has to be a channel that makes this relative price increase. Maggiori assumes that there are costs of exporting the foreign good that rise during bad times. This leads to a switch in demand toward US goods, which generates the rise in their relative price.

Gourinchas and Rey (2022) build a model in which the global economy can be in one of three states at any time: normal, fragile, and disaster. That study associates times of global stress with the fragile state. Investors in both countries can trade in equities and real bonds that pay off in terms of each country's consumption basket. US bonds are less risky because of their payoffs in the fragile and disaster states, so they earn on average a lower rate of return. During disaster periods, which are rare, there is a large drop in global output, and in addition, there is partial default on foreign bonds. When the economy enters into a fragile state from a normal state, the probability of disaster increases. To hedge the risk that occurs from holding foreign bonds in the disaster state, investors purchase Home bonds during fragile times. The trade deficit of the US increases during fragile times, allowing the US to increase demand for its own non-traded goods, leading to a real appreciation.

Jiang et al. (2020) posit that there is an exogenously given demand from abroad for US bonds because they are valued for their liquidity or some other special property. Bonds are issued by firms

[5] See also Bruno and Shin (2015), Bruno and Shin (2017), Du et al. (2018b), Dedola and Lombardo (2012), Dedola et al. (2013), Banerjee et al. (2016), Devereux and Yu (2020), Amador et al. (2020), Fanelli and Straub (2021), Chahrour and Valchev (2022) and Fang and Liu (2021).

[6] See He and Krishnamurthy (2013) for a general survey of how financial constraints affect and magnify the effective risk aversion of investors.

in the US, but these firms face a borrowing limit. Bonds are used to finance productive activity. The model can, for example, account for dynamics of real exchange rates in response to a monetary tightening in the US As the US raises interest rates, the debt issuing capacity of firms falls, reducing their output but also reducing their supply to the rest of the world of the liquid asset. The dollar appreciates both because of the increase in the interest rate and the higher liquidity return on the liquid bonds forced by the contraction in their supply. The study also considers the effects of a flight to dollars, which would also lead to an increase in the convenience yield and appreciation of the dollar. The paper emphasizes that if such a shock is accompanied by a monetary easing in the US, that the US trade balance could run into deficit even while the dollar was appreciating. This is driven by the increase in US wealth from the greater seignorage arising from the increase in the liquidity yield on bonds. In another experiment, the study considers a shock to productivity for US firms. This reduces the firms' borrowing capacity, reduces the supply of debt, and thus raises the convenience yield and appreciates the dollar. Foreign firms which hold some dollar debt have an adverse balance sheet effect, which is contractionary for their output.

Kekre and Lenel (2021) present a model of convenience yields and risk premia in a general equilibrium model of the global economy. The convenience yield arises from an ad hoc model in which agents have some preference for bonds issued by the US. The main drivers of global downturns are a disaster shock that is also correlated with a "safety shock" that changes the relative demand for US assets. In addition, there is nominal wage stickiness and monetary policy set by a Taylor rule. The model is quite rich, but some intuition can be gleaned by considering the effect of the safety shock alone, as global demand for US bonds tends to increase during global crises. The shift in demand toward US bonds tends to lower their rate of return. This leads to lower inflation in the US (relative to the rest of the world), which induces a monetary policy response that reduces the real interest rate, but this leads to a real appreciation of the dollar as the convenience yield is rising. On the goods market side, there is a drop in US consumption induced by the higher real wage (due to the deflationary bond demand), which in turn induces producers to supply less. The drop in supply outstrips the drop in consumption, so the relative price of US goods rises, consistent with the real appreciation given home bias in preferences.

Akinci et al. (2022) aims to explain the real appreciation of the dollar during times of uncertainty. The model features a US financial sector that takes in saving from US households and invests in US equities and foreign debt and a unconstrained foreign financial sector (the opposite of the set-up in Maggiori (2017).) There is no special role for US government debt. An increase in the volatility of US productivity leads to an increase in risk aversion in the US relative to the rest of the world. This shock causes US intermediaries to lower demand for foreign bonds, and they shed some of their holdings of foreign debt, contributing to a depreciation of the foreign currency.

Dahlquist et al. (2022) build a model in which agents have "deep habits" - an external habit for each good in the consumption basket. The key properties of these preferences is that they are not homothetic, and expenditure shares may vary as wealth and consumption levels change. In particular, the study assumes that US households are wealthier, and thereby less risk averse than those in other countries. During periods in which income and global consumption takes a turn downward, US consumption falls less than that in other countries, and because of home bias in consumption, the relative demand for goods produced in the US increases. This leads to a US real appreciation during bad times, which also makes US bonds a good hedge against global shocks.

Our model differs from much of the literature in that we examine a uniform global shock in a framework that feature endogenous convenience yield due to financial intermediary friction. Our main focus is on a global financial tightening. The asymmetry in the model arises not from the shock, but from the property that US government bonds are considered to be better collateral on banks' balance sheets. We emphasize the increase in the liquidity yield on these bonds, and the appreciation of the dollar that occurs because these bonds become more valuable during global downturns. In most respects, our model is a standard open-economy New Keynesian model, so it does not require the introduction of any new features, other than the special role of dollar debt, to account for the puzzles. Moreover, we find that in equilibrium there is retrenchment, which accounts for another possibly puzzling feature of the data.

Section 2 presents an empirical exchange rate instrumental variable regression analysis. Section 3 presents the model. Section 3 presents the model. The calibrated parameters are described in section 4 and section 5 describes the steady state. Section 6 examines the responses to a global financial tightening, to a global productivity shock, and to some unconventional monetary policy experiments. Section 7 compares the model implied moments with the data. Section 8 concludes.

2 Motivating facts

Figure 1 shows some stylized facts around time of the global financial crisis that helps to motivate the model. The upper panel shows the strong relationship of liquidity returns and the US dollar exchange rate. The blue line represents the US dollar price of the euro in the left panel and the US dollar price of the average of the rest of the G10 currencies in the right panel (converted into real exchange rates by adjusting for relative consumer prices.) The red line in both graphs presents the liquidity yield measure in Engel and Wu (2023), defined as the difference between a market rate of return and the rate of return on short-term government bonds for the US relative to the other country.[7] The measure captures the liquidity or convenience services of government bonds. The panel clearly illustrates that the sharp appreciation of the US dollar in the 2008 period

[7]This measure is used by Engel and Wu (2023) but is nearly identical to the ones that are used in the studies of Du et al. (2018a) and Jiang et al. (2021a). The G10 currencies are the US dollar, the euro, Australian dollar, Canadian dollar, Japanese yen, New Zealand dollar, Norwegian krone, Swedish krona, Swiss franc, and U.K. pound. The exchange rate and price data is from DataStream.

is associated with a large increase in the US liquidity yield, which implies an increase in demand for US Treasuries during the crisis.

The middle panel shows retrenchment during the crisis. The left (right) panel plots the ratio of capital inflows (outflows) to GDP respectively for the US, Germany and the rest of the G10 average.[8] Before 2008, there are regular inflow and outflow of roughly 10% of GDP. (Note that a positive amount of outflows from a country is plotted as a negative number in the right-hand-side panel.) During the global financial crisis period, highlighted in gray, there is a dramatic difference. Inflows into these countries turn from positive to negative, implying that investors from other countries are shedding their holdings of foreign (i.e., US, German, or G10, respectively) assets. The right panel tells a similar story, that US, German, or G10 investors are reducing their holdings of foreign assets, as signified by the fact that the outflow numbers become positive.

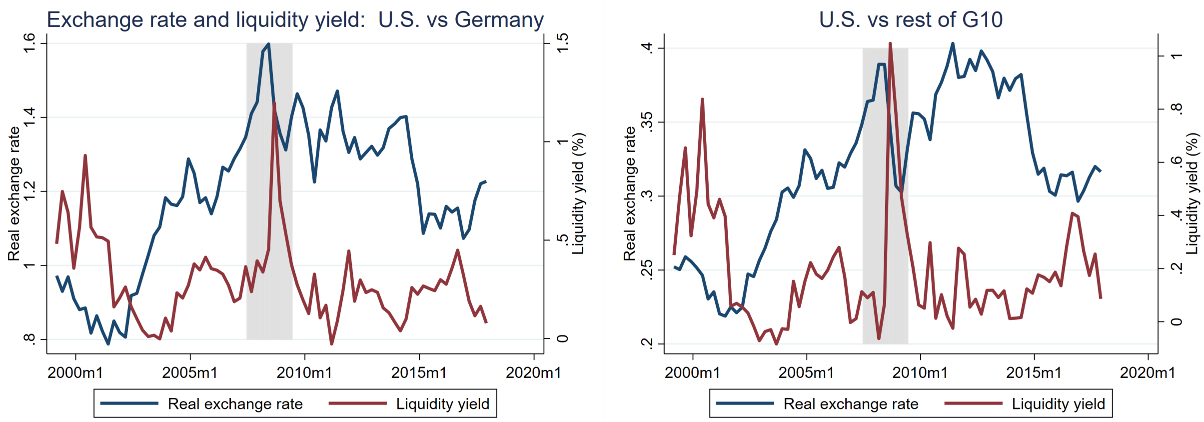
The last panel reports the dynamics of real variables of the US relative to the rest of the world. We look at three different ratios: the US GDP to world GDP ratio, the US consumption to world consumption ratio and the US investment to world investment ratio. The figure plots the first difference of these ratios. During the financial crisis, US GDP fell relative to the rest of the world (blue line). US consumption also fell relative to the rest of the world but less than the drop of the GDP ratio. Finally, there is a big drop in the relative US investment.

In addition to the well-known data on net capital flows, our model will offer some insights into these empirical regularities.

[8] The capital flow data is from Bluedorn et al. (2013).

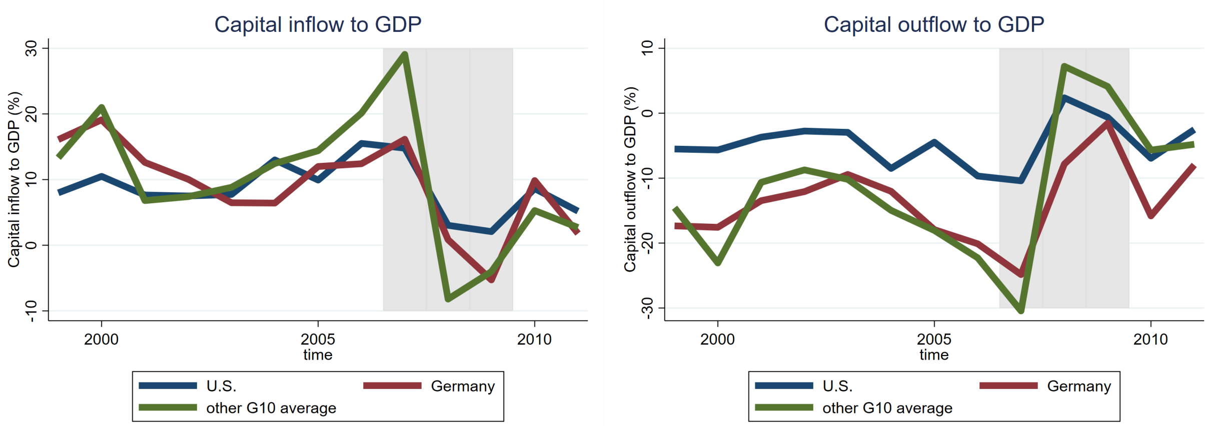
Figure 1: Stylized facts during the Global Financial Crisis

Upper panel



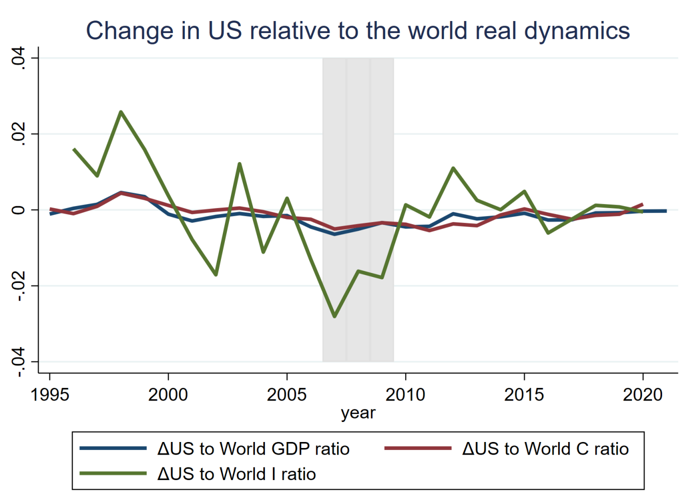
Note: Liquidity yield is defined as in Engel and Wu (2023), which is Home to Foreign market interest rate indifferential minus Home to Foreign government interest rate differential $(i_t^m - i_t^{m*} - (i_t^g - i_t^{g*}))$. The rest of the G10 means the G10 countries excluding the US and euro area.

Middle panel



Note: Following the convention, a capital outflow is defined as a negative value when outflow occurs.

Lower panel



Note: The three ratios are US GDP/World GDP, US consumption/World consumption and US investment/World investment. Data is annual and the first difference (Δ) is year-on-year difference.

3 Model

We describe a two country model, denoted Home and Foreign. The countries are symmetric in all dimensions except for the pledgeablility of government bonds. Agents supply labor and consume goods from both countries. The world is populated with a unit mass of agents and Home has share n of these, with Foreign share $1-n$. We assume that firms set prices in domestic currency (PCP) for home sales and foreign currency (LCP) for exports, and adjust prices constrained by Rotemberg-style price adjustment costs.

3.1 Households

There are two types of households, the Ricardian type (R), which has access to financial markets and the Keynesian (K) type, which are hand-to-mouth. The Keynesian type has a mass of m and the Ricardian has a mass of $1-m$.[9] Agents in the Home country have preferences over consumption and hours given by

$$U_j = \frac{(C_t^j)^{1-\sigma_j} - 1}{1-\sigma_j} - \frac{\chi}{1+\psi}(H_t^j)^{1+\psi_j} \tag{1}$$

where $j \in \{R, K\}$ represents the Ricardian and Keynesian households. Financial markets are restricted for households. Ricardian households can interact only with domestic banks in the form of non-contingent home currency denominated deposits. Banks in turn hold domestic and foreign currency denominated government bonds as well as domestic and foreign equity. The environment for banks is described further below.

The Ricardian agents' budget constraint is

$$P_t C_t^R + B_t = W_t H_t^R + R_t B_{t-1} + \Pi_t + TR_t - T_{s,t} \tag{2}$$

where P_t is the CPI in Home currency, B_t represents households deposits of domestic currency in the Home banking system, Π_t represents the net receipts that households receive from production firms and banks, and TR_t is a transfer made from the Home government to the households. Here, R_t is the domestic currency interest rate received by households on bank deposits. Finally, $T_{s,t}$ is the startup capital transferred to new banks at time t.

Keynesian agents have no access to capital markets, and have the budget constraint

$$P_t C_t^K = W_t H_t^K \tag{3}$$

Consumption for each type of household is a CES aggregate over home- and foreign-produced

[9] The presence of Keynesian agents helps to improve within-country unconditional moments in the model, discussed in Section 7 All the main results hold if we assume away the Keynesian agents ($m = 0$) in the IRF analysis in Section 6. We provide robustness check at Appendix C.4.

goods:

$$C_t^j = \left(\omega^{\frac{1}{\mu}} (C_{h,t}^j)^{1-\frac{1}{\mu}} + (1-\omega)^{\frac{1}{\mu}} (C_{f,t}^j)^{1-\frac{1}{\mu}}\right)^{\frac{1}{1-\frac{1}{\mu}}} \tag{4}$$

for $j \in \{K,R\}$ and where $\omega \geq n$, representing the possibility of home bias in preferences. Given this assumption, the Home CPI is written as

$$P_t = \left(\omega P_{h,t}^{1-\mu} + (1-\omega) P_{f,t}^{1-\mu}\right)^{\frac{1}{1-\mu}} \tag{5}$$

where $P_{h,t}$ ($P_{f,t}$) represents the Home currency price of Home (Foreign) goods.[10]

Optimal consumption of Home and Foreign goods for the Home consumer is

$$C_{h,t}^j = \omega \left(\frac{P_{h,t}}{P_t}\right)^{-\mu} C_t^j \text{ and } C_{f,t}^j = (1-\omega)\left(\frac{P_{f,t}}{P_t}\right)^{-\mu} C_t^j \tag{6}$$

Optimal labor supply is described by

$$W_t = \chi P_t (C_t^R)^{\sigma_j} (H_t^R)^{\psi} \tag{7}$$

In aggregate, we have

$$C_t = (1-m)C_t^R + (m)C_t^K, H_t = (1-m)H_t^R + (m)H_t^K$$

Given the return on deposits (R_{t+1}) and the utility discount factor (β_{t+1}), that are both known in time t, Home household's Euler equation is [11]

$$1 = E_t \beta_{t+1} R_{t+1} \Omega_{t+1} \tag{8}$$

The preferences, budget constraints, and optimal choices for the Foreign economy are analogous. The presence of home bias in Foreign preferences then implies that the price index for the Foreign economy is

$$P_t^* = \left(\omega^* P_{f,t}^{*1-\mu} + (1-\omega^*) P_{h,t}^{*1-\mu}\right)^{\frac{1}{1-\mu}} \tag{9}$$

[10] Letting $0 \leq x \leq 1$ represent the degree of home bias in preferences, where $x = 0$ ($x = 1$) represents zero (full) home bias, we can define $\omega = n + x(1-n)$.

[11] $\Omega_{t+1} \equiv (\frac{C_{t+1}^R}{C_t^R})^{-\sigma_R} \frac{P_t}{P_{t+1}}$. We allow for the possibility of a preference shock as a simple way to model demand shock in our model.

3.2 Firms

A measure n of firms in the Home economy produce differentiated goods. The aggregate Home good is a composite of these differentiated goods, where the elasticity of substitution in demand between individual goods is denoted as $\varepsilon > 1$. The production function for firm i in the Home country is

$$Y_{i,t} = A_t(L_{i,t}^{1-\alpha} K_{i,t}^{\alpha}) \tag{10}$$

where A_t is an aggregate productivity term. $K_{i,t}$ is the firm's use of capital, and $L_{i,t}$ the use of labor.

We assume that the firm in each country sets two prices, one for sales in the domestic market in the domestic currency, and one for sales in the export market in the local currency of the importer. Thus, both countries engage in 'local currency pricing' (LCP).

The profits of the Home firm i are then represented as

$$\Pi_{i,t} = \big((1+s_{i,t})(P_{i,h,t}Y_{i,h,t} + S_t P_{i,h,t}^{*} Y_{i,h,t}^{*}) - MC_t(Y_{i,h,t} + Y_{i,h,t}^{*})\big) \tag{11}$$

where $P_{i,h,t}$ is the price set in domestic currency for Home sales, and $P_{i,h,t}^{*}$ is the Foreign currency price, with S_t being the exchange rate (Home price of Foreign Currency). Also, MC_t denotes the firm's marginal cost, and $s_{i,t}$ represents a subsidy that may be given to the firm to offset the monopoly distortion in pricing. Cost minimization by the firm implies:

$$A_t(1-\alpha)(L_{i,t}^{1-\alpha}K_{i,t}^{\alpha})MC_t = W_t L_{i,t} \text{ and } A_t\alpha(L_{i,t}^{1-\alpha}K_{i,t}^{\alpha})MC_t = R_{K,t}K_{i,t} \tag{12}$$

The firm chooses its Home and Foreign price to maximize the present value of expected profits, net of price adjustment costs

$$E_t \sum_{j=0} \Omega_t \left(\Pi_{i,t} - \xi\left(\frac{P_{i,h,t}}{P_{i,h,t-1}}\right) P_{h,t}Y_{h,t} - \xi\left(\frac{P_{i,h,t}^{*}}{P_{i,h,t-1}^{*}}\right) S_t P_{h,t}^{*} Y_{h,t}^{*} \right) \tag{13}$$

where $\xi(.)$ represents a price adjustment cost function for the firm. We assume that $\xi'(.) > 0$, and $\xi''(.) > 0$. In the calibration, $\xi = \frac{\phi_\pi}{2}(\frac{P_{i,h,t}}{P_{i,h,t-1}} - 1)^2$. Price adjustment costs are proportional to the nominal value of Home sales to each of the Home and Foreign markets, to be consistent with the nominal profit objective function of the firm.

The first order conditions for profit maximization for the Home firm i can be described as

$$\begin{aligned}(1+s_{i,t})Y_{i,h,t} = {} & \varepsilon(P_{i,h,t}(1+s_{i,t}) - MC_t)\tfrac{Y_{i,h,t}}{P_{i,h,t}} + \xi'\left(\tfrac{P_{i,h,t}}{P_{i,h,t-1}}\right)\tfrac{1}{P_{i,h,t-1}}P_{h,t}Y_{h,t} \\ & - E_t\Omega_{t+1}\xi'\left(\tfrac{P_{i,h,t+1}}{P_{i,h,t}}\right)\tfrac{P_{i,h,t+1}}{P_{i,h,t}^2}P_{h,t+1}Y_{h,t+1}\end{aligned} \tag{14}$$

$$
\begin{aligned}
(1+s_{i,t})S_t Y^*_{i,h,t} = \quad & \varepsilon(S_t P^*_{i,h,t}(1+s_{i,t}) - MC_t)\frac{Y^*_{i,h,t}}{P^*_{i,h,t}} + \xi'\left(\frac{P^*_{i,h,t}}{P^*_{i,h,t-1}}\right)\frac{1}{P^*_{i,h,t-1}} S_t P^*_{h,t} Y^*_{h,t} \\
& - E_t \Omega_{t+1} \xi'\left(\frac{P^*_{i,h,t+1}}{P^*_{i,h,t}}\right)\frac{P^*_{i,h,t+1}}{P^{*2}_{i,h,t}} S_{t+1} P^*_{h,t+1} Y^*_{h,t+1}
\end{aligned}
\tag{15}
$$

3.3 Banks

Banks are modeled as in Gertler and Karadi (2011). A fraction of household members $1-\theta$ become bankers in any period, continue as bankers with probability θ, and revert to being consumers with probability $1-\theta$. When starting up, a bank receives some start up capital from households to establish its net worth, and borrows from households at fixed rates to invest in claims to capital (or equity), Home and Foreign currency denominated government bonds. Besides government, only banks operate in international financial markets. A Home banker i's balance sheet in period t is

$$
B_{i,t} + N_{i,t} = Q_t K_{h,i,t+1} + S_t Q^*_t K_{f,i,t+1} + D_{h,i,t} + S_t D_{f,i,t} \tag{16}
$$

where $B_{i,t}$ represents domestic currency deposits from households, $N_{i,t}$ is beginning net worth, Q_t and Q^*_t are the price of a unit of domestic and foreign capital, $K_{h,i,t+1}$ and $K_{f,i,t+1}$ are the holding of domestic and foreign capital, $D_{h,i,t}$ is the bank's purchase of Home denominated government bonds, and $D_{f,i,t}$ is it's purchase of foreign currency denominated government bonds. This says that bankers use their net worth and new debt to invest in the Home and Foreign capital and Home and Foreign bonds. We calibrate so that banks will hold a positive position in all assets.[12]

Banker i chooses $K_{h,i,t+1}$, $K_{f,i,t+1}$, $D_{h,i,t}$, and $D_{f,i,t}$ to maximize her value evaluated using the SDF of Home Ricardian households, $\Omega_{t+1} = \beta_{t+1}\frac{(C^R_{t+1})^{-\sigma}}{(C^R_t)^{-\sigma}}\frac{P_t}{P_{t+1}}$. Following Gertler and Karadi, conjecture that the value function of the bank is a time varying linear function of her net worth, so that $V_{i,t} = \upsilon_t N_{i,t}$

The banker's value function then satisfies:

$$
V_{i,t} = E_t \Omega_{t+1}\left((1-\theta)N_{i,t+1} + \theta V_{i,t+1}\right) \tag{17}
$$

This captures the fact that the banker will revert to being a consumer with probability $1-\theta$ and consume it's net worth, and continue to be a banker with probability θ. The net worth dynamics must satisfy

[12]In order to narrow the focus of the model, we abstract from foreign currency funding of banks. This important channel has been explored by Bruno and Shin (2015) and Avdjiev et al. (2019) among many others.

$$
\begin{aligned}
N_{i,t+1} &= \tilde{R}_{k,t+1}Q_{t+1}K_{h,i,t+1}+\tilde{R}^{*}_{k,t+1}Q^{*}_{t+1}S_{t+1}K_{f,i,t+1}+R_{h,t+1}D_{h,i,t}+S_{t+1}R_{f,t+1}D_{f,i,t}-R_{t+1}B_{i,t} \\
&= (\tilde{R}_{k,t+1}-R_{t+1})Q_tK_{i,t+1}+(\tfrac{S_{t+1}}{S_t}\tilde{R}^{*}_{k,t+1}-R_{t+1})S_tQ^{*}_tK_{i,t+1} \\
&\quad +(R_{h,t+1}-R_{t+1})D_{h,i,t}+(\tfrac{S_{t+1}}{S_t}R_{f,t+1}-R_{t+1})S_tD_{f,i,t}+R_{t+1}N_{i,t}
\end{aligned} \tag{18}
$$

Here, $\tilde{R}_{K,t+1} \equiv \frac{R_{K,t+1}+(1-\delta)Q_{t+1}}{Q_t}$ and $\tilde{R}_{K,t+1} \equiv \frac{R^{*}_{K,t+1}+(1-\delta)Q^{*}_{t+1}}{Q^{*}_t}$ are the net return on the Home capital where δ is the depreciation rate on capital, $R_{h,t+1}$ is the return on the domestic currency government bond and $R_{f,t+1}$ is the analogous return on the foreign government bond.

Banks maximize their value subject to (16) and subject to the participation constraint:

$$
\begin{aligned}
V_{i,t} \geq\; & \vartheta_t\left((\kappa_{h1}+\kappa_{h2}\tilde{D}_{h,t})D_{h,i,t}+(\kappa_{f1}+\kappa_{f2}S_t\tilde{D}_{f,t})S_tD_{f,i,t}\right) \\
&+\vartheta_t\left((\kappa_{Kh1}+\kappa_{Kh2}Q_t\tilde{K}_{h,t+1})Q_tK_{h,i,t+1}+(\kappa_{Kf1}+\kappa_{Kf2}S_tQ^{*}_t\tilde{K}_{f,t+1})S_tQ^{*}_tK_{f,i,t+1}\right)
\end{aligned} \tag{19}
$$

We introduce a set of asset-specific constraint parameters to allow for differential pledgeability as collateral across assets. Specifically, we have κ_{Kh1}, κ_{Kf1}, κ_{h1} and κ_{f1} as the constraint parameters for Home capital, foreign capital, Home bonds and Foreign bonds respectively[13]. As we discuss at length below, we posit that holdings of capital are more constrained than government bonds, and in turn, Foreign government bonds holdings are more constrained than Home bonds. The key idea is that government bonds are more pledgeable than equity or capital because of their safety and liquidity. In particular, the US Treasury is the most pledgeable asset because of its safety and the depth of its market.

The bank's first order conditions for, respectively, Home and Foreign government bonds and Home and Foreign capital, are given by

$$
E_t\Lambda_{i,t+1}\left(R_{h,t+1}-R_{t+1}\right)=\lambda_{i,t}\vartheta_t(\kappa_{h1}+\kappa_{h2}\tilde{D}_{h,t}) \tag{20}
$$

$$
E_t\Lambda_{i,t+1}\left(\frac{S_{t+1}}{S_t}R_{f,t+1}-R_{t+1}\right)=\lambda_{i,t}\vartheta_t(\kappa_{f1}+\kappa_{f2}S_t\tilde{D}_{f,t}) \tag{21}
$$

$$
E_t\Lambda_{i,t+1}\left(\tilde{R}_{k,t+1}-R_{t+1}\right)=\lambda_{i,t}\vartheta_t(\kappa_{Kh1}+\kappa_{Kh2}Q_t\tilde{K}_{h,t+1}) \tag{22}
$$

$$
E_t\Lambda_{i,t+1}\left(\frac{S_{t+1}}{S_t}\tilde{R}^{*}_{k,t+1}-R_{t+1}\right)=\lambda_{i,t}\vartheta_t(\kappa_{Kf1}+\kappa_{Kf2}S_tQ^{*}_t\tilde{K}_{f,t+1}) \tag{23}
$$

[13] We also introduce κ_{Kh2}, κ_{Kf2}, κ_{h2} and κ_{f2} so the constraint depends on the aggregate bank holding of the assets (denoted with $\tilde{D}_{h,t}$,$\tilde{D}_{f,t}$, $\tilde{K}_{h,t+1}$ and $\tilde{K}_{f,t+1}$). The idea is that the monitoring cost is increasing with the asset size. We set these parameter values very small (0.005). The main purpose of these parameters is to pin down a determinate steady state portfolio. This is discussed further in section 4 below. Since these terms depend on aggregate values we assume that individual banks take these as given in their portfolio decisions. In equilibrium $\tilde{D}_{i,t}=D_{i,j,t}$ and $\tilde{K}_{i,t}=K_{i,j,t}$ will hold.

Here, $\lambda_{i,t}$ is the Lagrange multiplier on the bank's participation constraint (19) and

$$\Lambda_{i,t+1} \equiv \Omega_{t+1}\left((1-\theta)+\theta\upsilon_{i,t+1}\right)$$

is the banker's effective SDF. The bank's value function can be retrieved from the envelope condition:

$$\upsilon_{i,t} = \frac{E_t \Lambda_{i,t+1} R_{t+1}}{1-\lambda_{i,t}} \tag{24}$$

Now we can use the fact that banks are homogeneous, and aggregate across all Home banks, adding the start up capital that is given to new banks, which we assume is $\varphi\left(Q_t K_{h,t+1} + S_t Q_t^* K_{f,t+1} + D_{h,t} + S_t D_{f,t}\right)$, to get the dynamics of total net worth for the domestic banking sector as:

$$\begin{aligned} N_{t+1} = \quad & \theta[(\tilde{R}_{k,t+1} - R_{t+1})Q_t K_{h,t+1} + (\tilde{R}^*_{k,t+1} - R_{t+1})S_t Q_t^* K_{f,t+1} \\ & +(R_{h,t+1} - R_{t+1})D_{h,t} + (\tfrac{S_{t+1}}{S_t} R_{f,t+1} - R_{t+1})S_t D_{f,t} + R_{t+1} N_t] \\ & +\varphi\left(Q_t K_{h,t+1} + S_t Q_t^* K_{f,t+1} + D_{h,t} + S_t D_{f,t}\right) \end{aligned} \tag{25}$$

3.4 Capital Goods Producers

Capital goods producers buy the unused capital from banks, and engage in new investment, and sell the new capital to banks at price Q_t. The representative capital goods producer has the profit function

$$Q_t I_t - P_t(I_t + I_t \psi(\frac{I_t}{I_{t-1}})) \tag{26}$$

where $\psi(.)$ is an adjustment cost function, satisfying $\psi'(.) > 0$ and $\psi''(.) > 0$, with $\psi(\delta) = 0$. In the calibration, $\psi = \frac{\phi_k}{2}(\frac{I_t}{I_{t-1}} - 1)^2$. This implies that the price of capital is

$$Q_t = P_t(1 + \psi'(\frac{I_t}{I_{t-1}})\frac{I_t}{I_{t-1}} + \psi(\frac{I_t}{I_{t-1}})) \tag{27}$$

3.5 Monetary policy

We assume a Taylor rule where the Central Bank targets the CPI inflation rate and uses the government interest rate as an instrument:

$$R_{h,t+1} = \frac{1}{R_{h,ss}}\left(\frac{P_t}{P_{t-1}}\right)^{\eta^{\pi}(1-\rho^R)} (R_{h,t})^{\rho^R} M_t \tag{28}$$

where M_t is an exogenous monetary shock, η^{π} and ρ^R are respectively the inflation targeting parameter and the interest rate smoothing parameter for the Central Bank

3.6 Fiscal policy

The Home and Foreign governments make transfers to the households and subsidize firms by issuing government debt. For the Home country we have

$$\bar{D}_{h,t} = R_{h,t}\bar{D}_{h,t-1} + s_t(P_{h,t}Y_{h,t} + S_t P^*_{h,t}Y^*_{h,t})) + TR_t \tag{29}$$

where $\bar{D}_{h,t}$ is the total outstanding debt of the Home government, assumed to be exogenous. In the baseline analysis, we assume governments issue a constant amount of debt every period.

3.7 Balance of Payments

The profit of the Home production firms are

$$\begin{aligned} \Pi^p_t = \quad & \Big((1+s_t)(P_{h,t}Y_{h,t} + S_t P^*_{f,t}Y^*_{h,t}) - MC_{h,t}(Y_{h,t} + Y^*_{h,t}) \\ & -\xi_t\left(\tfrac{P_{h,t}}{P_{h,t-1}}\right)P_{h,t}Y_{h,t} - \xi_t\left(\tfrac{P^*_{h,t}}{P^*_{h,t-1}}\right)S_t P^*_{h,t}Y^*_{h,t}\Big) \end{aligned} \tag{30}$$

Given constant returns to scale, we can write $MC_{h,t}(Y_{h,t} + Y^*_{h,t})$ as

$$W_t L_t + r_{K,t}K_t$$

In equilibrium, labor supply must equal labor demand, so that

$$H_t = L_t$$

The profit of Home capital producing firms is:

$$\Pi^K_t = Q_t I_t - P_t(I_t + I_t\psi(\frac{I_t}{I_{t-1}})) \tag{31}$$

In addition, the capital stock accumulation equation must satisfy

$$K_{t+1} = I_t + (1-\delta)K_t$$

where δ is the depreciation rate on capital.

Total profits from the corporate non-financial sector are then

$$\Pi^p_t + \Pi^K_t$$

In addition, the return on deposits to Home households may be expressed as

$$R_t B_{t-1} = r_{K,t} K_{h,t} + (1-\delta) Q_t K_{h,t} + r^*_{K,t} K_{f,t} + (1-\delta) S_t Q^*_t K_{f,t} + R_{h,t} D_{h,t-1} + S_t R_{f,t} D_{f,t-1} - N^e_t \tag{32}$$

where N^e_t represents the net worth of existing banks. The startup capital transferred from households to banks is

$$T_{s,t} = \varphi \left(Q_t K_{t+1} + D_{h,t} + S_t D_{f,t} \right) \tag{33}$$

So total net worth of the banking sector at time t is $N_t = N^e_t + T_{s,t}$

Finally, government transfers are:

$$TR_t = \bar{D}_h - R_{h,t} \bar{D}_h - s_t (P_{h,t} Y_{h,t} + S_t P^*_{h,t} Y^*_{h,t})) \tag{34}$$

Note that the net deposits from households to financiers can be defined as

$$B_t = Q_t K_{h,t+1} + S_t Q^*_t K_{f,t+1} + D_{h,t} + S_t D_{f,t} - N_t$$

Putting together (30), (31), (32), (33), (34), with the Home budget constraint (2), we get the balance of payments condition:

$$\begin{aligned} P_t(C_t + I_t + I_t \psi(\tfrac{I_t}{I_{t-1}})) + D_{h,t} - \bar{D}_h + S_t D_{f,t} + Q_t(K_{h,t} - K_t) + S_t Q^*_t K_{f,t} = \\ P_{h,t} Y_{h,t} - \xi(\tfrac{P_{h,t}}{P_{h,t-1}}) P_{h,t} Y_{h,t} + S_t P^*_{h,t} Y^*_{h,t} - \xi(\tfrac{P^*_{h,t}}{P^*_{h,t-1}}) S_t P^*_{h,t} Y^*_{h,t} \\ + R_{h,t-1}(D_{h,t-1} - \bar{D}_h) + S_t R_{f,t-1} D_{f,t-1} + \tilde{R}_{k,t}(K_{h,t-1} - K_{t-1}) + S_t \tilde{R}^*_{k,t} K_{f,t-1} \end{aligned} \tag{35}$$

where $\bar{D}_{h,t}$ is the total outstanding debt of the Home government.

3.8 Adjusted UIP condition

By combining equation (20) and (21) we get:

$$E_t \Lambda_{t+1} \left(\frac{S_{t+1}}{S_t} R_{f,t+1} - R_{h,t+1} \right) = \lambda_t \vartheta (\kappa_{f1} - \kappa_{h1}) \tag{36}$$

Equation (36) indicates that the presence of differential balance sheet constraints leads to a deviation from UIP. Given that the US bond requires less collateral than that of the Foreign country, there is a positive convenience yield on the US asset.[14] Moreover, the convenience yield will be time varying, critically dependent on the degree of financial stress captured by the Lagrange multiplier

[14] We omit the second order terms from this illustration since they are negligible for our quantitative results.

on the bank's incentive constraint.

Log linearizing the equation, we have a UIP condition adjusted for the balance sheet friction:

$$E_t s_{t+1} - s_t = (r_{h,t+1} - r_{f,t+1}) + \hat{\eta}_t \tag{37}$$

where $\hat{\eta}_t$ is our definition of convenience yield.[15]

Our emphasis is on demand for liquidity rather than risk. Linearizing the equation eliminates the role of a time-varying risk premium, which also may play a role in driving exchange rates.[16] Forward iterating the equation gives:

$$s_t = -E_t \sum_{j=1}^{\infty} (r_{h,t+j} - r_{f,t+j} - (\overline{r_h - r_f})) - E_t \sum_{j=0}^{\infty} (\tilde{\eta}_{t+j} - (\overline{\eta})) + \lim_{k\to\infty} (E_t s_{t+k} - k(\overline{s_{+1} - s})) \tag{38}$$

or in real terms:

$$rer_t = -E_t \sum_{j=1}^{\infty} (\tilde{r}_{h,t+j} - \tilde{r}_{f,t+j} - (\overline{\tilde{r}_h - \tilde{r}_f})) - E_t \sum_{j=0}^{\infty} (\tilde{\eta}_{t+j} - (\overline{\tilde{\eta}})) + \lim_{k\to\infty} (E_t rer_{t+k} - k(\overline{rer_{+1} - rer})) \tag{39}$$

where rer_t is the linearized real exchange rate and variables with tilde is the real variable normalized by the country's CPI.

This shows that the transitory component of the exchange rate appreciates in response to the sum of expected future (transitory) interest rate differentials, as is usual, but also to the sum of expected future (transitory) convenience yields.

4 Calibration

The model frequency is quarterly. We calibrate the model to match US moments. We think of Home as the US and Foreign as the rest of the World. To highlight the important role of the asymmetric collateral value, we set all other parameters to be equal across Home and Foreign. The parameter values are summarized in Table 1.

The parameters can be partitioned into two blocs. The first bloc is externally set and mostly set to values that are in line with standard literature values. The second bloc is calibrated to match some long-term averages in the data.

[15] Specifically,$\hat{\eta}_t$ depends on the change in the bank's Lagrange multiplier, and the change in the conditional expectation of the bank's SDF. It is identically zero when $\kappa_{h1} = \kappa_{f1}$.

[16] See, for example, Kalemli-Özcan and Varela (2021); Akinci et al. (2022); Obstfeld and Zhou (2023) for empirical evidence linking risk, UIP deviations, and exchange rates.

On the household side, we set the discount factor (β) to be a constant and is 0.99. Home bias (ω, ω^*) parameters are set at 0.8. The cross-country elasticity of substitution of goods (μ) is set at 3.8, following Bajzik et al. (2020). The within-country elasticity of substitution of goods (ε) is assumed to be 6. The inverse of the Frisch elasticity (ψ) is set at 1 and we calibrate the disutility of labor χ to match a steady-state H^* of 0.33. The size of Keynesian households (m) is set at 0.3, according to Kaplan et al. (2014). The CRRA coefficient for Ricardian and Keynesian households (σ_R and σ_K) are set as 5 and zero respectively.[17]

On the production side, the country mass (n) is set at 0.5 to preserve symmetry. The Rotemberg price adjustment cost (ϕ_π) is set at 155.88, matching an annual probability of price change of 0.84 in a Calvo-type model of sticky prices. The investment adjustment cost (ϕ_k) is set at 0.9. The capital share (α) is set at 0.33 and depreciation rate (δ) is set at 0.04.

On the government side, the Taylor coefficient (η^π) is set at 1.5 with a smoothing parameter (ρ^R) equal to 0.85 (taken from Justiniano et al. (2010)). Government debt is fixed ($\bar{D}_h$ and $\bar{D}_f$) at a constant value of 2.7, resulting in a steady state Home debt to GDP ratio ($\bar{D}_h/GDP$) of 84%, matching the long-run average of the US. The monopoly subsidy is set at 0.2 ($s = \frac{1}{\varepsilon-1}$) to eliminate the steady state mark-up distortion. For simplicity, gross steady state inflation ($\bar{\pi}$) is set to zero.

On the banking side, we calibrate the bond constraint parameters to match the US external positions. This is the only source of asymmetry between the two countries. We calibrate the four bond constraint parameters (κ_{h1},κ_{f1}, κ^*_{h1}, κ^*_{f1}) to match a steady state convenience yield of 1% at an annual rate (which is the same as steady state Home minus Foreign interest rate differential of -1%), a steady state positive income account of +0.0013 ((current account - trade balance)/GDP of US from 1990-2019), a steady state -18.5% NFA position and a steady state Foreign holding of US government bond ($D^*_h/\bar{D}_h$) of 45% (average from Tabova and Warnock (2021)). While these are calibrated jointly, lowering the Home bond constraint parameter (κ_{h1} and κ^*_{h1}) relative to the Foreign bond constraint parameter (κ_{f1} and κ^*_{f1}) generates a positive convenience yield. Since the net foreign bond position is defined as $-D^*_{h,t} + S_t D_{f,t}$, a relatively low value of κ^*_{h1} to κ_{f1} is useful to generate a negative NFA position. A higher κ^*_{h1} (relative to κ_{h1}) helps to match the 45% share of Foreign holdings of US Treasury obligations. Finally, the relative values of κ_{h1} and κ_{f1} are useful for pinning down the positive income account. On the capital side, we maintain an agnostic view about the relative collateral values in generating the asymmetry of external positions. Instead, we calibrate the model such that $\kappa_{K,h} = \kappa^*_{Kf} < \kappa_{Kf} = \kappa^*_{Kh}$. That is, Home capital serves as better collateral than Foreign capital for Home banks and the opposite is true for Foreign banks. We set $\kappa_{Kf} = \kappa^*_{Kh} = 0.49$ and $\kappa_{Kh} = \kappa^*_{Kf} = 0.41$ to match a net equity return of 5.7% and equity

[17] Since the Keynesian housholds do not conduct intertemporal trade, the coefficient σ_K only appears in the optimal labor supply decision. Setting $\sigma_K = 0$ is identical to GHH preferences in which the wealth effect of labor supply is muted. We make this assumption to obtain a realistic procyclical labor supply for the Keynesian housholds. Appendix C.4 shows that the key results in the IRF analysis do not depend on this assumption.

Home share of 70% (average of 1990-2016 from Hnatkovska (2019)), which are in the range of estimates from the equity premium puzzle and Home equity bias literatures. We normalize the country specific collateral constraint parameters (ϑ, ϑ^*) to be 1. Finally, we set the bank survival probability (θ) and capital injection rate (φ) to be at standard values of 0.95 and of 0.01 respectively, resulting in a steady state leverage of around 3.

The bond constraints also include the parameters (κ_{h2}, κ_{f2}, κ^*_{h2}, κ^*_{f2}). Our analysis is based on linearization around the non-stochastic steady state. In the non-stochastic steady state, in the absence of these parameters, the equilibrium portfolio would be indeterminate, as investors would be indifferent between assets that paid the same expected return inclusive of the liquidity yield. The problem is similar to the indeterminacy of portfolios in the non-stochastic steady state in the mean-variance framework (see Devereux and Sutherland (2010, 2011).) While it is necessary to introduce these terms, we set all four at very small values (0.005) so as to have effectively no influence on the dynamic adjustment process. This is somewhat analogous to the fix proposed by Schmitt-Grohé and Uribe (2003) of introducing a debt-elastic interest rate to solve the problem of the absence of a steady state in small-open economy models with incomplete markets. An alternative approach would be to solve the model using some sort of higher-order approximation, such as the "non-stochastic steady state" used in the closed economy model of Gertler et al. (2012). The steady-state portfolios in such a set-up would be chosen as the solution to a mean-variance criterion. But this type of model has proven to be notably unsuccessful in capturing important features of international portfolio holdings, specifically the high degree of home bias in equity holdings and the relatively higher return that the US earns on its foreign portfolio compared to other countries. Our choices of (κ_{h1}, κ_{f1}, κ^*_{h1}, κ^*_{f1}), as described above, are chosen to more nearly approximate those features of the data. This makes our calibration of the steady state closer in spirit to the models that introduce a makeshift "preferred habitat" into portfolio choice (such as in Greenwood et al. (2020) and Gourinchas et al. (2022)), or the empirical models in which the factors affecting portfolio choice are data-driven (Koijen and Yogo (2020); Jiang et al. (2022).)

We first focus on the analysis of global shocks in the impulse response analysis in section 6 and allow for country specific shocks in section 7. We first introduce three shocks. They are global productivity shocks (A_t^{Global}), global financial shocks (ϑ_t^{Global}), and global monetary shocks (M_t^{Global}). All shocks features a AR(1) stochastic property:

$$log(A_t) = log(A_t^*) = log(A_t^{Global}) = \rho^{A,Global} log(A_{t-1}^{Global}) + s^{A,Global} e_t^{A,Global}$$

$$log(\vartheta_t) = log(\vartheta_t^*) = log(\vartheta_t^{Global}) = \rho^{\vartheta,Global} log(\vartheta_{t-1}^{Global}) + s^{\vartheta,Global} e_t^{\vartheta,Global}$$

$$log(M_t) = log(M_t^*) = log(M_t^{Global}) = \rho^{M,Global} log(M_{t-1}^{Global}) + s^{M,Global} e_t^{M,Global}$$

We set the persistence of TFP shock and financial shock to be 0.98 and the persistence of monetary shock to be 0.25. In the impulse response analysis, we focus on 1% shocks unless specified.

Table 1: Parameter values

	Symbol	Value	Meaning / description	Target
	Households			
1	β	0.99	Discount factor	
2	σ	5	CRRA risk coefficient	
3	m	0.3	Size of hand to month households	
4	$\omega = \omega^*$	0.8	Home bias	
5	χ	14.85	Labor disutility	$L^* = 0.333$
6	ψ	1	Inverse of Frisch elasticity	
7	μ	3.8	Cross country elasticity of substitution	Bajzik et al. (2020)
8	ε	6.0	Within country elasticity of substitution	
	Firms			
9	n	0.5	Home country mass	
10	α	0.33	Capital share	
11	ϕ_π	155.88	Price adjustment cost	Calvo probability = 0.84
12	ϕ_k	0.9	Investment adjustment cost	
	δ	0.04	Depreciation rate	
	Governments			
13	$\bar{\pi}$	1	Steady state inflation	
14	$s = s^*$	0.2	Monopoly subsidy ($\frac{1}{\varepsilon-1}$)	
15	$\bar{D}_h = \bar{D}_f$	2.7	Total government debt	Debt/GDP = 84%
16	η^π	1.5	Taylor rule coefficient	
17	ρ^R	0.85	Interest rate smoothing parameter	
	Banks			
18	$\vartheta = \vartheta^*$	1	Country-specific constraint value	
19	κ_{h1}	0.025	Home bank constraint value on Home bond	Jointly targeting: $D_h^*/\bar{D}_h$ = 45%,
20	κ_{f1}	0.401	Home bank constraint value on Foreign bond	NFA/GDP = -18.5%,
21	κ_{h1}^*	0.05	Foreign bank constraint value on Home bond	Net foreign income/GDP = 0.13%,
22	κ_{f1}^*	0.32	Foreign bank constraint value on Foreign bond	1% convenience yield
23	κ_{Kh}	0.41	Home bank constraint value on Home capital	Equity premium 5.7%
24	κ_{Kf}	0.49	Home bank constraint value on Foreign capital	
25	κ_{Kh}^*	0.49	Foreign bank constraint value on Home capital	Home bias of equity 70%
26	κ_{Kf}^*	0.41	Foreign bank constraint value on Foreign capital	
27	θ	0.95	Bank survival prob.	
28	φ	0.01	Bank starting networth	

Table 2: Steady state values

Symbol	Targeted steady state
$r_f - r_h$	1% (annualized)
Net foreign income: (CA-TB)/GDP	0.13% (annualized)
NFA/GDP	-18.5% (annualized)
$D_h^*/\bar{D}_h$	45%
$\bar{D}_h/Y$	84% (annualized)
Home bank's Home equity share ($\frac{K_h}{K_h+SK_f}$)	70%
Foreign bank's Foreign equity share ($\frac{K_f^*}{K_f^*+K_h^*/S}$)	71%
$\tilde{R}_k = \tilde{R}_k$	5.7% (annualized)

Symbol	Steady state value	Symbol	Steady state value
C	0.6113	d_h	1.482
C^*	0.6107	d_f	0.964
K	4.895	λ	0.0093
K^*	4.906	λ^*	0.0094
L	0.331	r_h	1.0114
L^*	0.333	r_f	1.0139
W	1.630	$r = r^*$	1.0101
W^*	1.628	Home bank's leverage (asset/equity)	3.01
RER	0.9993	Foreign bank's leverage (asset/equity)	2.99
Y	0.806	Home's external equity share ($\frac{K_f}{K_f+D_f}$)	61%
Y^*	0.808	Foreign external equity share ($\frac{K_h^*}{K_h^*+D_h^*}$)	53%

5 Steady state values

The model is solved by linearizing around the non-stochastic steady state so there is no risk premium and we can solely focus on the mechanism via convenience yield. Table 2 presents some steady state values using the parameterization listed above. The complete set of equations and steady state conditions provided in Appendix A and B.

The only asymmetry of the model is the bond constraint parameters. As we noted above, we set the Home bond to be better collateral for both Home and Foreign banks ($\kappa_{h1}, \kappa_{h1}^* < \kappa_{f1}, \kappa_{f1}^*$). With only this asymmetry, we are able to generate three important features of the US external position. First, the US has a government rate that is lower than the Foreign government rate by 1%. This can be understood by looking at steady state version of equation (37). Since $E_t s_{t+1} - s_t = 0$ at the steady state, the excess monetary return of the Foreign bond reflects the additional non-pecuniary balance sheet cost of holding it. This demonstrates the convenience yield arising from the better pledgeability of US debt.

Second, the US has a negative NFA position, meaning that it has a net liability to the rest of the world. Third, despite the net liability, the US has a steady state trade balance deficit and positive income account. This is because while it owes the rest of the world repayment, it pays a lower interest rate on its liability to the rest of the world than the rest of the world pays to the US. Also, the external equity share of the Home country is higher than the Foreign country (defined as external equity divided by the sum of external equity and bond holdings). The means that the Home country earns a higher overall return on foreign assets due to the equity premium, as documented in Bertaut et al. (2023). The sum of these features leads to the US enjoying an exorbitant privilege that follows from the presence of the convenience yield.

The asymmetry in pledgeability or acceptability as collateral has macroeconomic implications. The US has a higher steady-state consumption than the rest of the world (0.6113 vs 0.6107). While the steady state capital is the same, the US has lower steady state employment and a higher steady state wage than the rest of the world. Taken together, this implies that while the US produces less than the rest of the world, it lives with a higher consumption and wage levels purely due to the "seigniorage" from the exorbitant privilege. On the financial side, we observe that the US banks have a higher leverage than the rest of the world (3.01 vs 2.99) but less tight constraint, reflected by a lower λ in the steady state (0.0093 vs 0.0094).

6 Impulse responses

6.1 *Global Financial Shock*

In this section, we describe a series of impulse responses from the simulated model. As a baseline, in Figure 2 we allow for a uniform increase of one percent in ϑ and ϑ^*, the tightness parameter on the capital market constraint (see equation 19). This represents a negative shock to the banking system in each country, requiring a higher bank value for all types of collateral and forcing the banks to de-lever as well as adjust their investment across asset classes. This could be thought of as a sudden loss in confidence in the value of banks' collateral. For example, Bernanke (2018) , Gorton and Metrick (2012) and Perri and Quadrini (2018) make the case that in the early stages of the Global Financial Crisis, financial intermediaries lost confidence in the value of collateral put up by other agents

The shock to the financial constraint leads to an immediate appreciation of the US real exchange rate, followed by an expected depreciation. As described in equation (39), the real exchange rate can be decomposed as the sum of expected future real interest rate differentials and convenience yield differentials. Column 3 of the first row of Figure 2 shows that this is predominantly associated with a rise in the convenience yield (defined as negative of $\tilde{r}_{ht} - \tilde{r}_{ft} - (rer_{t+1} - rer_t)$, the blue line in the top panel third column).[18] Thus, there is an increase in the deviation from UIP; the excess expected return on Foreign relative to US government bonds rises in response to the global financial shock. To understand the mechanics of this response, take the difference between equation (20) and equation (21) for the Home bank, which gives the condition:

$$E_t \Lambda_{i,t+1} \left(R_{h,t+1} - R_{f,t+1} \frac{S_{t+1}}{S_t} \right) = \lambda_{i,t} \vartheta_t (\kappa_{h1,t} - \kappa_{f,1,t}) \tag{40}$$

The term inside the parenthesis on the right hand side is negative, given that the Home bond is better collateral than the Foreign bond.[19] The expected return on the Home bond is less than that of the Foreign bond, so that on average, UIP will not hold, as in the data. Given a negative financial shock (a rise in ϑ_t), the impact on the left-hand side of this equation must be negative, so that the expected return on the Home bond must fall relative to that on the Foreign bond - hence the convenience yield on US government bonds rises further. While this explanation uses the first-order conditions for the Home bank alone, a similar explanation holds for the Foreign bank. Therefore a direct implication of the asymmetric collateral value of US relative to Foreign government debt is that a uniform tightening of global financial conditions leads to an increase in the convenience yield on US bonds and a real appreciation of the US dollar.[20]

We can examine Figure 2 in more detail to track the macroeconomic responses to the negative financial shock. The response of λ_t and λ_t^* represent the endogenous increase in the Lagrange multipliers on the bank's collateral constraints. While this increases for both countries, it increases more for the Home bank than the Foreign bank. This is due to three different channels. First, the Home bank leverages more at the steady state and has a higher equity portfolio, resulting in a bigger fall in net worth following the financial tightening. Second, the dollar appreciation raises the value of the Foreign banks' Home investments but hurts the Home bank's Foreign investments. Third, the Home bank disinvests in physical capital more than the Foreign bank, given the advantage of Home bonds over Foreign bonds, and the fact that the relative balance sheet cost of Home bonds to capital for the Home bank is less than the equivalent relative cost for the Foreign bank. We can see the intuition behind this third channel by focusing on equations (22) and (20) above, and the

[18] Note that if we measure the relative convenience yield as in Engel and Wu (2023), the difference between the deposit rate in the US and the government bond interest rate, relative to the same interest rate differential in the Foreign country, that also increases at the time of the financial shock (row 1, column 4.) This is in agreement with the empirical regularities plotted in Figure 1.

[19] In this description, we abstract from the quadratic terms in the collateral constraint and the first order conditions 20 and 21, since in practice these terms are very small, and do not affect the argument.

[20] In fact, given the monetary rule, the interest rates on Home and Foreign bonds do not change very much, as can be seen in Figure 2 top right panel. Instead, the increase in the convenience yield on US bonds is mostly achieved by an immediate appreciation and therefore an expected depreciation of the Home real exchange rate.

equivalent conditions for the Foreign bank. This gives us the conditions:

$$E_t \Lambda_{i,t+1} \left(\tilde{R}_{k,t+1} - R_{ht+1} \right) = \lambda_{i,t} \vartheta_t (\kappa_{Kh1} - \kappa_{h1}) \tag{41}$$

$$E_t \Lambda^*_{i,t+1} \left(\tilde{R}^*_{k,t+1} - R_{ft+1} \right) = \lambda^*_{i,t} \vartheta_t (\kappa^*_{Kh1} - \kappa^*_{f1}) \tag{42}$$

Equation (41) describes the Home bank's trade off between Home government bonds and Home capital (or equity), while equation (42) describes the analogous trade-off for the Foreign bank between Foreign government bonds and Foreign capital. The negative financial shock reduces investment in both countries, but investment falls by more in the Home country. The term $(\kappa_{Kh1} - \kappa_{h1})$ in parentheses on the right hand side of equation (41) is larger than the equivalent term $(\kappa^*_{Kh1} - \kappa^*_{f1})$ in equation (42) precisely because Home government bonds represent better collateral, relative to Home capital, than Foreign government bonds relative to Foreign capital. Hence the expected excess return on Home capital relative to Home bonds must rise more than that on Foreign capital relative to Foreign bonds, and the end result is that Home investment must fall relative to Foreign investment. With sticky prices and demand determined output, this translates to a greater fall in Home output relative to Foreign output.[21]

Figure 2 shows that US NFA to GDP falls sharply after the financial shock. This is primarily due to real appreciation of the US dollar. We can interpret this as the US effectively making a transfer to the rest of the world as part of it's 'exorbitant duty' during a financial crisis.[22] As part of this transfer, Home consumption falls relative to Foreign consumption, as shown in row 4 column 3. But despite the wealth transfer and the larger fall in Home consumption, we do not encounter the Maggiori (2017) 'reserve currency paradox', which questions how the US dollar country can appreciate during times when US relative wealth falls, since in principle with home bias in preferences, the fall in relative consumption should cause a US terms of trade depreciation. As we've shown here the real dollar appreciation is driven in financial markets by the rise in the convenience yield. While this still has to be reconciled on the goods side, LCP introduces a separation between the real exchange rate and terms of trade movement. As shown in the bottom right panel of Figure 2, the real exchange rate appreciation is almost wholly driven by deviations from the law of one price. This is similar to a 'trade wedge' explanation in Maggiori (2017) whereby the deviations

[21] While this argument seems incomplete because both Home and Foreign banks invest in bonds and capital in each others country, the fact that in both equity capital and bond holdings banks have relative larger positions in their Home market ensures that the financial shock hits Home investment more than it does Foreign investment. Abbassi and Bräuning (2023) and Agarwal (2019) have recently empirically investigated how credit contractions in the financial sector influence investment in an international setting.

[22] Separately, it can be shown that the Home trade balance initially deteriorates, since Home output falls by more than the fall in consumption and investment, but this is followed by an improvement in the trade balance after two quarters.

widened during the crisis. Here in fact the larger drop in Home output upon the global financial shock results in a small terms of trade improvement, rather than deterioration.[23,24]

The response to a global financial shock in our model helps to throw light on some outstanding puzzles in the literature on the role of the US dollar in financial crises. First, we see an explanation for the appreciation of the dollar during times of financial contraction. If there were only risk motives for holding bonds, the reserve currency paradox arises. If the dollar is a good asset to hold because it appreciates during times of global stress, what factors lead to its appreciation? It cannot be that investors buy more insurance at that point (that is, buy more US bonds) because once the downturn happens, it is too late to buy insurance. The paradox is that the US must make its insurance payment to foreigners during these global financial recessions, but that implies a reduction in US wealth, which in a standard model ought to lead to a real depreciation. In our model, these difficulties are resolved. The demand for dollar assets increases in bad times because of the increase in demand for the asset that provides better collateral when financial constraints are tightened. And with local-currency pricing, the link between the terms of trade and the real exchange rate is broken, and so even if US relative wealth falls, a real appreciation is still possible.

The asymmetric response of Home and Foreign banks also has a striking implication for gross asset holding positions. Given that the Home bank increases its demand for Home bonds as it substitutes away from capital, there is an external portfolio retrenchment - Home banks increase their holding of Home bonds and decrease their holdings of Foreign bonds, and the opposite applies to the Foreign banks. Retrenchment is a common feature of financial crises and was clearly a feature of the Global Financial Crisis. To understand the forces driving retrenchment, it is instructive to look at the response to the same financial shock, except in the case when there is no difference in collateral requirements between the Home and Foreign bank. Figure 3 illustrates this case, where $\kappa_{h1} = \kappa^*_{h1} < \kappa_{f1} = \kappa^*_{f1}$. While the US (i.e. Home) government bond still has a collateral advantage, the collateral constraints are identical for both Home and Foreign banks, so there is no home bias in bond holdings among banks. To understand the forces driving retrenchment, note first that because the banks in each country face identical constraints on US and Foreign bonds, in essence at steady state their holdings of US bonds and Foreign bonds are nearly identical.[25] The tightening of the credit constraint raises demand for US bonds relative to Foreign bonds because US bonds are preferred collateral. If all investors were identical and evaluated assets in the same currency, given that the supplies of bonds from both countries are fixed, the increase in demand would lower

[23] We study the implications of different pricing in subsection 6.4.

[24] The real exchange rate appreciation and the fall in the value of Home capital translates into a greater fall in the net worth of Home banks relative to Foreign banks, which can be interpreted as another way in which the US acts as an implicit 'insurer' to the rest of the world in times of global crisis, given that banks are owned by domestic residents

[25] There is a slight difference arising from the fact that US wealth is somewhat higher in steady state because of the seignorage it earns from its exorbitant privilege.

the expected return on US bonds relative to Foreign bonds until investors were satisfied to hold the existing stock of both bonds. However, in reality, the appreciation of the dollar raises the foreign currency value of US bonds, and by itself increases the share of those bonds in the Foreign bank's portfolio. Given that the Foreign bank has increased its share of US bonds in this way, the US bank can, in equilibrium, increase the share of US bonds in its portfolio by buying some from the Foreign bank. The fact that the US bank has a stronger incentive to switch its portfolio out of capital and into Home bonds further reinforces the retrenchment. The relative reduction in demand for Foreign bonds works in the opposite way. The depreciation of the foreign currency automatically reduces the share of Foreign bonds in the US bank's portfolio, so the Foreign bank balances the market by buying some Foreign bonds from US banks.[26]

This helps towards a better understanding of asset flows. The literature has puzzled over how to reconcile the empirical finding of global retrenchment during times of financial stress with the observation that the dollar appreciates. Retrenchment seems to imply that while the US is shifting its demand away from Foreign assets, the rest of the world is shifting its demand away from dollar assets. But as we have seen, that understanding of retrenchment mixes the equilibrium change in asset holdings with the change in demand. We see that Foreign banks do increase their demand for US assets, as do US financial intermediaries, and that contributes to the appreciation of the dollar. But it is the change in the exchange rate itself as well as the influence of changes in demand for other assets that leads to the equilibrium portfolio adjustment - with Foreign banks reducing their holdings of US bonds, while US banks increase theirs.[27]

It is instructive to compare these results to some of the stylized facts in the response to financial shocks, as described in Davis and van Wincoop (2022). They estimate the response of asset prices and capital flows after a global financial shock (their "GFC factor.") They find that this leads to a global fall in equity prices, a global fall in real interest rates, and a retrenchment in capital flows. As we've seen, all these are features of our model following a global financial shock. In addition, Davis and van Wincoop (2022) find asymmetric effects for countries that are net debtors of safe assets. That is, they find that for the US, the current account improves, savings increases relative to the rest of the world, investment declines relative to the rest of the world, the US sells fewer Treasury bonds abroad, and the US sheds holdings of risky foreign assets. Again, all these features are captured by our model.

[26] Portfolio dynamics upon the global financial shock are reported in Appendix C.3. We also show results are robust to a special case in which capital is not traded internationally in Figure 11 in the Appendix.

[27] In a panel study of 188 countries, Kim and Min (2022) find that relative valuation effects among countries are mostly associated with exchange-rate changes (rather than asset price changes), and that there tends to be a negative correlation between real exchange rates and trade balances (that is, the trade balance tends to rise into surplus when the currency appreciates, as above.)

6.2 *Global Monetary Contraction*

Figure 4 illustrates an equal unexpected monetary contraction in the US and Foreign country.[28] This may provide insight into the aggressive monetary tightening cycle followed by many countries in 2022. In a symmetric environment a uniform monetary shock across the Home and Foreign country has no impact on the exchange rate when UIP holds. But here the model implies a dollar appreciation and a wider UIP deviation following the global shock. Even though the direct effect of the uniform shock is for both countries to raise their interest rates equally, the effects on the exchange rate, expected returns, and the policy instrument itself are not equal in equilibrium. The tightening monetary policy reduces aggregate demand and lowers the value of capital/equity. It also lowers the net worth of the banks that own capital, tightening the balance sheet constraint.[29] As with the global financial shock, the effect of the more stringent constraint is to raise the demand for US dollar bonds globally. The convenience yield on these bonds increases, and result in a real dollar appreciation through the second term on the right hand side of equation (39) despite the fact that the sum of interest rate differentials hardly moves at all. The disinflationary effect is stronger in the US because banks there are more incentivized to switch out of equities investments and into US bonds, thus lowering aggregate demand to a greater extent. Figure 4 also illustrates that capital flow retrenchment is a feature of a global monetary contraction, just as in the case of a global financial tightening.

6.3 *Global Productivity Shock*

Figure 5 presents the effects of a 1% global decline in TFP, which illustrates how a global slowdown arising from a productivity slowdown may have similar effects on the value of the dollar and the dollar liquidity premium. The effects on exchange rates, asset prices, and capital flows is mostly very similar to the effects of a tightening of the financial constraint. That is because the drop in productivity reduces the profitability of the bank, and so endogenously tightens the lending constraint. As in the literature on the "financial accelerator" (e.g., Bernanke and Gertler (1989), Kiyotaki and Moore (1997), Bernanke et al. (1999), Gertler and Kiyotaki (2010), Gertler and Karadi (2011)), the financial squeeze resulting from a TFP decline reduces investment and exacerbates the effects of the original drop in productivity on real output and employment. As in the case of an increase in ϑ and ϑ^*, the drop in global productivity (a 1% initial decline in A_t and A_t^*) leads to a tightening of the lending constraint as can be seen by the increase in the multipliers, λ_t and λ_t^*.

[28] In Appendix C, we also present the case of US monetary policy tightening.

[29] The collapse of Silicon Valley Bank serves as a pertinent example of this valuation channel. While the model accounts for valuation changes primarily through equity prices and exchange rate movements, the Silicon Valley Bank case involves a valuation change in long-maturity bonds, a factor which is absent in our model.

Because the US bond is relatively less constrained, demand for it increases, which lowers the expected return on the bond. This is mainly accomplished through an appreciation of the dollar, leading to an expectation of a depreciation. There is a larger decline in investment in the US for the same reason described above for a financial shock, leading to a larger decline in US output.

6.4 *Alternative Assumptions on Price Setting*

Figure 6 shows how the results are dependent on the assumption that retail prices are set in the currency of the buyer, i.e. LCP. The figure illustrates the impact of the same financial shock as in Figure 2 but now assuming that all goods prices are set in the seller's currency, (PCP), so that the firm in each country sets only one price in the domestic currency . The most notable difference from the baseline case is the much smaller response of the real exchange rate. With PCP, real exchange rate appreciation can occur only due to terms of trade appreciation, in combination with home bias in consumer preferences. In Figure 6, despite the fact that Home consumption falls relative to Foreign consumption, we do observe terms of trade appreciation in response to the financial shock. This is due to the larger drop in US output. But the resultant real exchange rate appreciation is much smaller than in the baseline case. The Figure also shows that the real convenience yield is mostly driven by the differential in real interest rates across countries rather than expected real exchange rate depreciation, as in the baseline case. Of course, in this case, there is no deviation from the law of one price in traded goods. This exercise shows that while the collateral advantage and convenience yield channel alone are enough to generate a dollar appreciation, LCP is quantitatively important by allowing the dollar to appreciate via the deviation from LOOP instead of terms of trade movements.

Figure 7 looks at the case with purely flexible prices. The Figure shows a very small real exchange rate appreciation. On the financial side, the appreciation happens because of a rise in the convenience yield. However, this is largely compensated by changes in government bond rates directly and therefore only partially accomplished through changes in the exchange rate. On the goods market side, this can occur only due to terms of trade appreciation. The terms of trade appreciates here because of a rise in Home consumption relative to Foreign consumption during the crisis. This highlights a "seignorage" effect similar to Jiang et al. (2020). When the convenience yield rises during the crisis, the US is able to finance its debt at a lower rate. When this effect is large enough, it boosts US consumption and overturns the recession effect. While our production economy model is substantially different from Maggiori (2017), this flexible price case illustrates the same 'reserve currency paradox'.[30]

We can conclude from these two figures that a complete analysis of the impact of a global financial shock that can account for the response of the US convenience yield, the real appreciation of the US dollar, and the feature of global portfolio retrenchment requires the combination of capital constrained banks, an advantage in collateral value for US bonds, as well as sticky prices with limited exchange rate pass-through, captured by a local currency pricing rule for exporting firms.

6.5 *Quantitative tightening and exchange rate intervention*

We next examine the implications of quantitative tightening (QT) and exchange rate (FX) intervention in our model. The interesting insight of this exercise is that it demonstrates that the central bank effectively has two separate instruments at its disposal, which do not have identical influences on the domestic or global economy.[31] For example, in 2021-2022, the US Federal Reserve responded to rising inflation by raising its policy rate, as our model for the monetary policy rule captures. At the same time, it also embarked on quantitative tightening. One effect of combining these two policies is a strong appreciation of the dollar because both the higher interest rate and the reduction in liquidity work to raise the value of the dollar. In fact, the dollar appreciated so strongly during this period that the exchange rate became a major concern of the rest of the world, and then unavoidably for US policymakers. Our analysis suggests that a different menu of interest-rates and balance sheet polices may have improved outcomes.

We postulate that the Home country conducts quantitative tightening and the Foreign country conducts FX intervention. To do so, we define new variables for the central bank balance sheets, where $d_{h,t}^{CB}$ and $d_{h,t}^{CB*}$ are the Home and Foreign central bank holding of Home bonds, $d_{f,t}^{CB*}$ is the Foreign central bank holding of Foreign bonds, and $K_{h,t}^{CB}$ is the Home central bank holding of Home capital. We assume $d_{h,t}^{CB}$ and $d_{h,t}^{CB*}$ follow an log AR 1 process with a persistence parameter ρ of 0.7:

$$log(d_{h,t}^{CB}) = \rho log(d_{h,t-1}^{CB}) + \varepsilon_t^{d_h^{CB}} \text{ and } log(d_{f,t}^{CB*}) = \rho log(d_{f,t-1}^{CB*}) + \varepsilon_t^{d_f^{CB*}}$$

The modified market clearing conditions are:

$$\text{Home bond market clearing: } \bar{d}_h = d_{h,t} + d_{h,t}^* + d_{h,t}^{CB} + d_{h,t}^{CB*}$$

[30] In Maggiori (2017)'s endowment economy setting, the global financial crisis is represented by a uniform drop of Home and Foreign output. With home bias, terms of trade and exchange rate are tightly connected to relative consumption. When output is endogenous, Home and Foreign output might not drop uniformly but it is relatively close in the flexible prices case.

[31] The potential for quantitative easing policies to operate separately from interest rate policy in the presence of financial frictions has been widely recognized, e.g. Gertler and Karadi, 2010, Bernanke, 2020.

$$\text{Foreign bond market clearing: } \bar{d}_f = d_{f,t} + d^*_{f,t} + d^{CB*}_{f,t}$$

$$\text{Home capital market clearing: } K_t = K_{h,t} + K^*_{h,t} + K^{CB}_{h,t}$$

The central banks' balance sheet are:

$$\text{Home central bank: } d^{CB}_{h,t} + q_t K^{CB}_{h,t} = 0$$

$$\text{Foreign central bank: } d^{CB*}_{h,t} + RER_t d^{CB*}_{f,t} = 0$$

A quantitative tightening, or large-scale asset sale, in this model will be an increase in $d^{CB}_{h,t}$ and the equivalent sales of $q_t K^{CB}_{h,t}$. Normally, one specifies quantitative intervention by the central bank as altering the amount of reserves held in the system, but our set-up does not specifically include central bank reserves as an asset. However, we subscribe here to the argument of Rogoff (2017) that for the consolidated government budget, reserves held at the central bank are essentially identical to short-term bonds issued by the government. When reserves pay interest, they are a debt obligation of the central bank, which then reduces the amount of "profit" from its portfolio that the central bank remits to the general government revenue each year. In other words, the implications for the overall budget are identical to those from issuing short-term bonds. The fact that in the US there have been only very slight differences between interest paid on reserves and interest on the shortest-term Treasury bonds suggests that these two assets are considered to be close substitutes. In our framework, when $d^{CB}_{h,t}$ increases, it is equivalent to the central bank reducing reserves held by the banking system. The central bank satisfies its balance sheet by selling off some of its less liquid assets, which in our model are represented by the government holdings of equities.[32]

Since the convenience of the Home bond is higher than capital, a QT operation is lowering the aggregate liquidity of assets in the private sector. On the other hand, a foreign exchange accumulation is an increase in $d^{CB*}_{h,t}$ and equivalent sales of $RER_t d^{CB}_{f,t}$. Figure 8 reports the IRFs of a 1% QT shock. As mentioned, the QT shock reduces aggregate liquidity. This results in a rise in the excess demand for the most pledgeable asset, therefore a rise of Home convenience yield and an appreciation of the US dollar. The drain of liquidity is also associated with a drop in world output due to a fall in capital price that lowers the banking net worth.

Figure 9 reports the IRFs of a 1% FXI shock where the Foreign central bank buys more bonds (accumulation of reserves). Similar to a QT shock, an FXI accumulation also reduces aggregate

[32] Note also that in the US QT is normally characterized by the central bank selling some of its holdings of Treasury bonds and reducing its reserve liabilities to private banks, while here we assume the central bank is selling equity and buying government bonds. But our interterpretation is consistent with actual QT in the sense that the central bank is swapping a less liquid asset (equity) for the more liquid asset (government bonds). See Dedola et al. (2021) for an empirical study of quantitative easing and its effects on exchange rates and international spillovers.

liquidity. Therefore there is a rise of Home convenience yield and an appreciation of the US dollar. The drain of liquidity is also associated with a drop in world output because the banking sector is more constrained than before.[33]

7 Model simulation

In this section, we compare the model-simulated moments with data moments to validate the model's relevance. The first exercise examines an empirical regression, while the second exercise delves into unconditional exchange rate moments.

Before turning to the exercises, we need to introduce more shocks to explain the data moments. We allow for country-specific shocks. In addition to TFP, financial, and monetary shocks, we allow for a discount rate shock (β_t, β_t^*) to represent demand-driven business cycle movements.

For any shock $J \in \{\beta, \vartheta, A, M\}$, we have:

$$log(J_t) = log(J_t^{Global}) + log(J_t^H) \, , log(J_t^*) = log(J_t^{Global}) + log(J_t^F),$$

$$\begin{aligned} log(J_t^{Global}) &= \rho^{J,Global} log(J_{t-1}^{Global}) + s^{J,Global} e_t^{J,Global}, \\ log(J_t^H) &= \rho^{J,H} log(J_{t-1}^H) + s^{J,H} e_t^{J,H}, \\ log(J_t^F) &= \rho^{J,F} log(J_{t-1}^F) + s^{J,F} e_t^{J,F} \end{aligned}$$

where $e_t^{J,H}$ and $e_t^{J,F}$ are Home and Foreign country specific shocks and $e_t^{J,Global}$ is a global shock, and $s^{i,j}$ represents a standard deviation scaling factor.

We assume that Home and Foreign shocks have the same persistence and standard deviations. We use standard values for productivity and monetary shocks. We set the persistence of all TFP processes $(\rho^{A,H}, \rho^{A,F}, \rho^{A,Global})$ to be 0.98 and standard deviations of H, F and $Global$ shocks to be 0.0032, 0.0032 and 0.0095 $(s^{A,H}, s^{A,F}, s^{A,Global} = 0.0032, 0.0032, 0.0095)$, implying a 0.9 correlation between Home and Foreign TFP.

We set the persistence of all monetary processes $(\rho^{M,H}, \rho^{M,F}, \rho^{M,Global})$ to be 0.25 and the standard deviations to be 0.002, 0.002 and 0 $(s^{M,H}, s^{M,F} = 0.002, s^{M,Global} = 0)$ so that cross-

[33]There are some similarities of this analysis and that of Fanelli and Straub (2021). In both models, the central bank gains an additional instrument that allows it to conduct sterilized intervention because of balance sheet constraints facing the banking sector. However, in our set-up, the constraints take a different aspect because of the special role of the dollar, and our analysis is embedded in a two-country set-up that then permits us to see explicitly the spillover effects of sterilized intervention. Our analysis also bears some resemblance to that of Bianchi et al. (2021), who emphasize the liquidity demand for dollars from the financial intermediation sector. As we have mentioned above, that study lays down different microfoundations for liquidity demand and the general equilibrium model is very simplified, not allowing for in-depth analysis of the potential real effects of conventional and unconventional monetary policy.

country monetary shocks are uncorrelated.

The balance sheet constraint (financial) shocks are assumed to have a persistence ($\rho^{\vartheta,H}, \rho^{\vartheta,F}, \rho^{\vartheta,Global}$) of 0.98 and standard deviations of 0.035 ($s^{\vartheta,H}, s^{\vartheta,F}, s^{\vartheta,Global} = 0.035$) so the implied cross-country correlation is 0.5, which is targeted to match the empirical correlation of Home and Foreign investment.

Finally, we set the preference shock persistence at 0.98 and standard deviation to be 0.007, 0.007 and 0 ($s^{\beta,H}, s^{\beta,F} = 0.007, s^{\beta,Global} = 0$) so that preference shock explains about 70% of consumption changes, consistent with the estimation result of Smets and Wouters (2003).

To capture the possibility of crisis periods, we model the financial shock flexibly with a Markov switching process with two states: a low volatility state with standard deviation values described above and a high volatility state in which the standard deviations are eight times the values in the low volatility state ($0.035 \times 8 = 0.28$). The Markov transition matrix is

$$P^{MK} = \begin{array}{c} L \\ H \end{array} \begin{bmatrix} 0.98, & 0.02 \\ 0.17, & 0.83 \end{bmatrix}$$

so the half-life of the low state is roughly eight to nine years and the half life of the high state is about one year.

7.1 Regression Comparison

In the first exercise, we follow the regression strategy from Engel and Wu (2023).[34] The regression specification is outlined as follows:

$$\Delta s_{j,t} = \alpha_j + \beta_1 s_{j,t-1} + \beta_2 \Delta\eta_{j,t} + \beta_3 \Delta(i - i^*)_{j,t} + \beta_4 \eta_{j,t-1} + \beta_5 (i - i^*)_{j,t-1} + u_{j,t} \tag{43}$$

where s is the nominal exchange rate of the dollar price of a unit of foreign currency, η is a measure of the convenience yield and $(i - i^*)$ is the US minus Foreign government bond interest rate differential. For the empirical estimation we consider a panel exchange rate series of the US dollar vs rest of the G10 currencies obtained from FRED. The convenience yield and interest rate data are obtained from Du et al. (2018a) and we use the shortest tenor available, which is 3-month, starting from January 1999 to January 2018. The convenience yield is measured as the payoff of a synthetic dollar government bond that is constructed by buying the Foreign government bond and hedging the exchange rate exposure by entering a forward contract (covered interest parity deviation of government bonds). Since the US government bond and the synthetic dollar

[34] Since one of the exercises is regression in daily frequency, the specification here differs slightly from that of Engel and Wu (2023) in that the error-correction term - the lagged exchange rate - is nominal rather than real.

government bond both pay dollar returns, the difference between the two gives a measure of the relative difference in liquidity services of the US and Foreign government bonds.

We compare the results from this regression to the same regression estimated on model-simulated data. The quarterly model is simulated for 15,000 quarters, and the first 100 periods are dropped.

Table 3 reports the coefficient estimates. In column (1), the empirical estimates for the changes in convenience and the interest rate differential are -1.65 and -2.61, respectively. This indicates that a 1% increase in convenience yield or interest rate differential (annualized) is associated with a 1.65% or 2.61% increase in the exchange rate compared to the previous quarter. In column (2), the model-implied coefficients for the changes in convenience yield and the interest rate differential are -1.15 and -2.45. These coefficients are reasonably close to, and within one standard deviation of the empirical counterparts. These untargeted moments provide support for our model and its quantitative calibration.

Table 3: Model implied regression and the empirical counterpart

$$\Delta s_{j,t} = \alpha_j + \beta_1 s_{j,t-1} + \beta_2 \Delta\eta_{j,t} + \beta_3 \Delta(i-i^*)_{j,t} + \beta_4 \eta_{j,t-1} + \beta_5 (i-i^*)_{j,t-1} + u_{j,t}$$

	Panel quarterly regression of G10 currenices	Model implied regression	Panal daily IV regression of G10 currenices
	(1)	(2)	(3)
$\Delta\eta_{j,t}$	-1.65**	-1.15	-9.07**
	(0.76)		(4.53)
$\Delta(i-i^*)_{j,t}$	-2.61***	-2.45	-8.58**
	(0.97)		(3.86)
$\eta_{j,t-1}$	-2.08**	-0.03	-0.002
	(0.87)		(0.002)
$(i-i^*)_{j,t-1}$	-0.44**	-0.004	-0.040
	(0.22)		(0.03)
s_{t-1}	-0.06**	-0.02	-0.003
	(0.02)		(0.002)
Observations	739	14,900	1746

Notes: Standard errors in parentheses are clusted by time. * p<0.1, ** p<0.05, *** p<0.01. Model implied regression is performed with 15,000-quarter observations and burning the first 100 quarters. In column (3), the first stage regression uses four financial shock measures in Ottonello and Song (2022) as the instruments for the change of convenience yield. The first stage F-statistics is 14.60.

The measured convenience yield in column 1 of Table 3 likely represents the response to multiple shocks, as does our simulated regression. The results from Section 6.1 focus solely on the role of the convenience yield in the response to a global financial shock. It is therefore of some interest to isolate such a precise response in the data. We follow a similar regression methodology as in equation (43) but now using a measure of the convenience yield that is driven uniquely by a global financial shock. To provide direct evidence of the mechanism from banking to exchange rates, we employ an instrumental variable regression. We instrument the change of convenience yield $\Delta\eta_{j,t}$ using financial shocks constructed by Ottonello and Song (2022), which are high-frequency changes in the market value of US intermediaries' net worth in a narrow 60-min window around their earnings announcements. In our model, a financial shock changes the US banks' net worth, which changes their demand for liquid and convenient assets, therefore creating a shift in the convenience yield. We make use of all four measures of financial shock in Ottonello and Song (2022) as our first stage instruments. They are the market value change of the earnings release bank around announcements, market value change of the all sample banks around announcements, and broader measures of these two which include earnings releases announced after market closed. For this exercise, we use daily changes in exchange rates (rather than quarterly in the first two columns) from 10-Jan-2001 to 29-Jul-2014.[35]

The regression estimates are reported in column 3 of Table 3. The coefficient on $\Delta\hat{\eta}_{j,t}$ is significantly negative. The coefficient of -9.07 indicates a 1% increase in the convenience yield driven by a global financial shock is associated with 9.07% appreciation of the US dollar. Again, we find that both the change of the convenience yield and the change of the interest rate differential are significant explanatory variables for exchange rate movements. More importantly, the instrumental variable regression highlights the convenience yield movement that is driven by change in banking net worth. We interpret this as evidence that banking demand for liquidity plays an important role in determining exchange rates through endogenous movements in the convenience yield.

7.2 Moment Comparison

In the second exercise, we report long-run moments of the model in Table 4. Column (1) contains the empirical moments of the US and Eurozone data from 1999Q1 to 2023Q1. Columns (2) to (4) represent the model-implied moments. As in the previous exercise, we simulate the model for 15,000 periods. Column (2) and column (4) display moments from realized paths where the simulated economies are always in the low volatility state and the high volatility state, respectively. Column (3) presents moments from a realized path that allows for the state to switch according to the Markov transition matrix.

The unconditional moments in column (3) indicate that the model can generate volatile exchange rate movements. The standard deviation of exchange rate changes is 2.5 times and 2 times

[35] Daily data helps to eliminate the effects of "left-out" variables in the regression that might play a role in exchange rate movements at longer frequencies, but do not much effect higher-frequency changes. In the first stage regression, the F-statistic for the joint significance of the instruments is 14.60. The Hansen J-statistic for correlation of the instruments with the error term in the second-stage regression is 7.21 with a p-value of 0.065. Our sample size is limited by the data we use as instruments described below, which was kindly provided to us by the authors of Ottonello and Song (2022). .

more volatile than output and consumption and is particularly high in the high volatility state (4.2 and 5.3). Additionally, the exchange rate is also much more volatile than the interest rate differential. The model can also generate a slightly negative regression coefficient (Fama's β) of Δs_{t+1} on $R_{h,t} - R_{f,t}$ that is close to the data. The coefficient is more negative when the model is conditional on the high volatility state. While it focuses on the global financial shock, Figure 2 provides some insight into the negative Fama's β. Following the shock, the Home - Foreign nominal interest rate falls because the Home economy has lower output and smaller inflation pressure than the Foreign economy. The dollar appreciates initially and is expected to depreciate afterwards. So when the financial shock is the dominant shock in the high volatility state, a fall in the Home - Foreign interest rate is associated with the expected depreciation of the dollar, resulting in a negative Fama's β.

The model can produce a realistic Backus and Smith (1993) correlation ($\rho(\Delta q, \Delta c - \Delta c^*)$) of 0.16. Focusing on the low volatility state, the model is able to generate a negative correlation between the real exchange rate change and relative consumption growth. This is driven by the discount rate shock. When Home households are relatively impatient, they experience higher consumption growth and currency appreciation due to home bias in consumption. When the financial shock becomes the dominant factor in the high volatility state, dollar appreciation goes hand-in-hand with a wealth transfer from the US to the rest of the world. This risk-sharing mechanism, which we emphasize in the IRFs analysis, leads to a relative consumption drop in the US and a positive Backus-Smith correlation.

The model also performs reasonably well in other moments, such as the persistence of the real exchange rate and realistic business cycle moments. Overall, the model can replicate important exchange rate and business cycle moments. The flexibility of the Markov switching modeling provides an explanation for various empirical estimates for some exchange rate moments such as Fama's β over different samples, as documented by Engel et al. (2022).

In Appendix D, we report the same table but with PCP setting and no collateral advantage of the US bonds. We find that these specifications produce less realistic moments, such as less volatile exchange rate, positive Fama's β (withouth collateral advantage) and much more volatile trade balance (with PCP). These robustness exercises highlight the importance of these key assumptions to generate realistic moments.

Table 4: Long-run moments

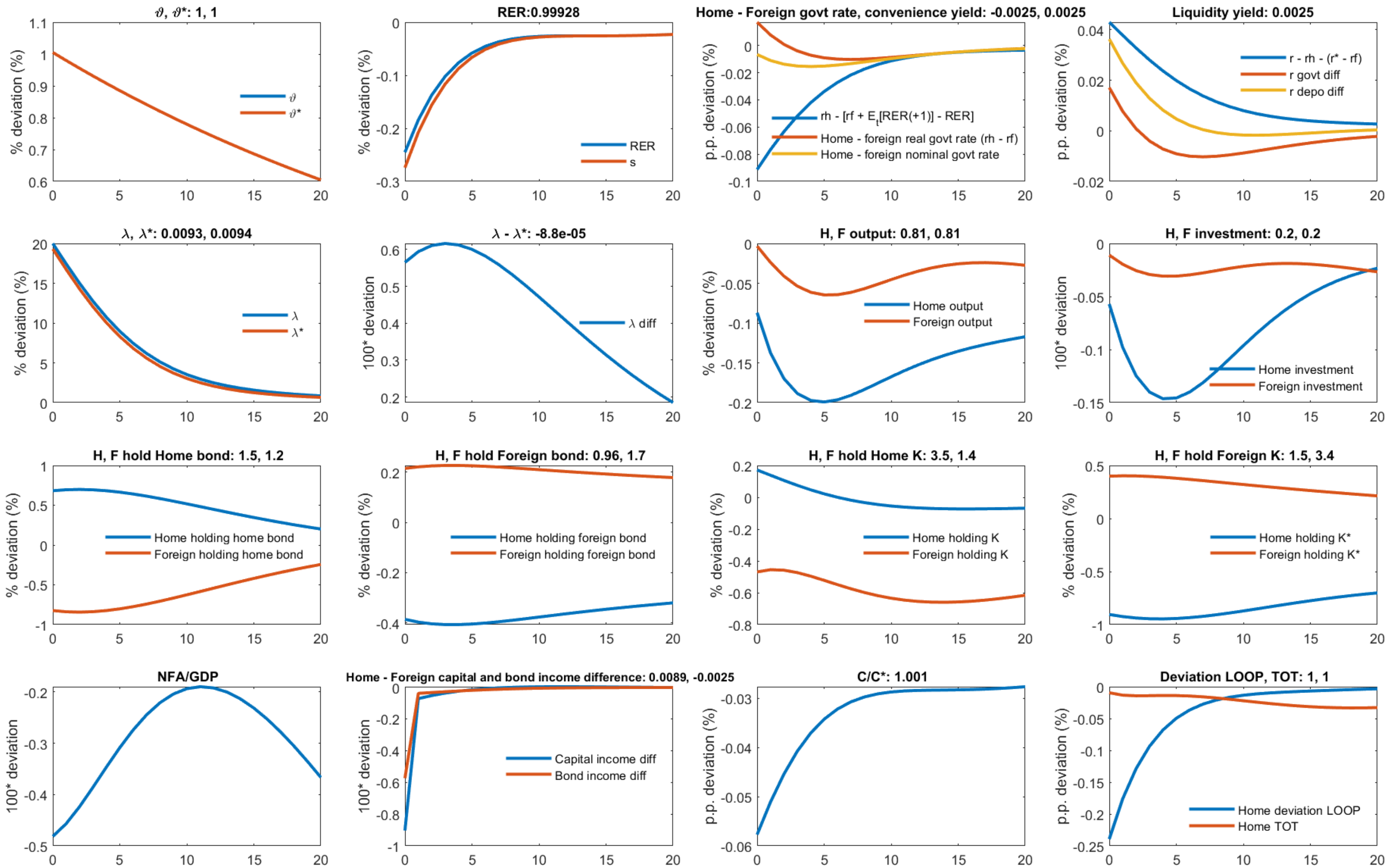
	Data moments of Eurozone vs US	Model moments conditional on the low volatility state	Model moments unconditional	Model moments conditional on the high volatility state
	(1)	(2)	(3)	(4)
Exchange rates				
$\sigma(\Delta s)/\sigma(\Delta GDP)$	3.6	1.6	2.5	4.2
$\sigma(\Delta s)/\sigma(\Delta c)$	3.3	1.1	2.0	5.3
$\sigma(i-i^{*})/\sigma(\Delta s)$	0.07	0.27	0.19	0.15
Fama β	-0.18	0.48	-0.03	-0.63
$\rho(\Delta q, \Delta c - \Delta c^{*})$	0.05	-0.01	0.16	0.54
$\sigma(\Delta q)/\sigma(\Delta s)$	0.99	0.91	0.93	0.93
Persistence				
$\rho(\Delta s)$ (NER)	-0.03	-0.07	-0.09	-0.13
$\rho(q)$ (RER)	0.93	0.95	0.89	0.79
$\rho(i-i^{*})$	0.95	0.93	0.95	0.98
$\rho(i)$	0.97	0.99	0.99	0.99
Trade balance				
$corr(\Delta nx, \Delta q)$	-0.06	0.62	0.76	0.94
$\sigma(\Delta nx)/\sigma(\Delta q)$	0.07	0.39	0.27	0.20
Business cycle				
$\sigma(\Delta c)/\sigma(\Delta GDP)$	1.1	1.4	1.2	0.8
$\rho(\Delta c, \Delta GDP)$	0.94	0.83	0.78	0.60
$\rho(\Delta I, \Delta GDP)$	0.81	0.60	0.66	0.87
$\rho(\Delta GDP, \Delta GDP^{*})$	0.88	0.66	0.56	0.25
$\rho(\Delta c, \Delta c^{*})$	0.90	0.06	0.05	0.01
$\rho(\Delta I, \Delta I^{*})$	0.55	0.53	0.54	0.74

Notes: Data moments are computed quarterly from 1999Q1 to 2023Q1. Model implied moments are performed with 15,000-quarter observations and burning the first 100 quarters.

8 Conclusions

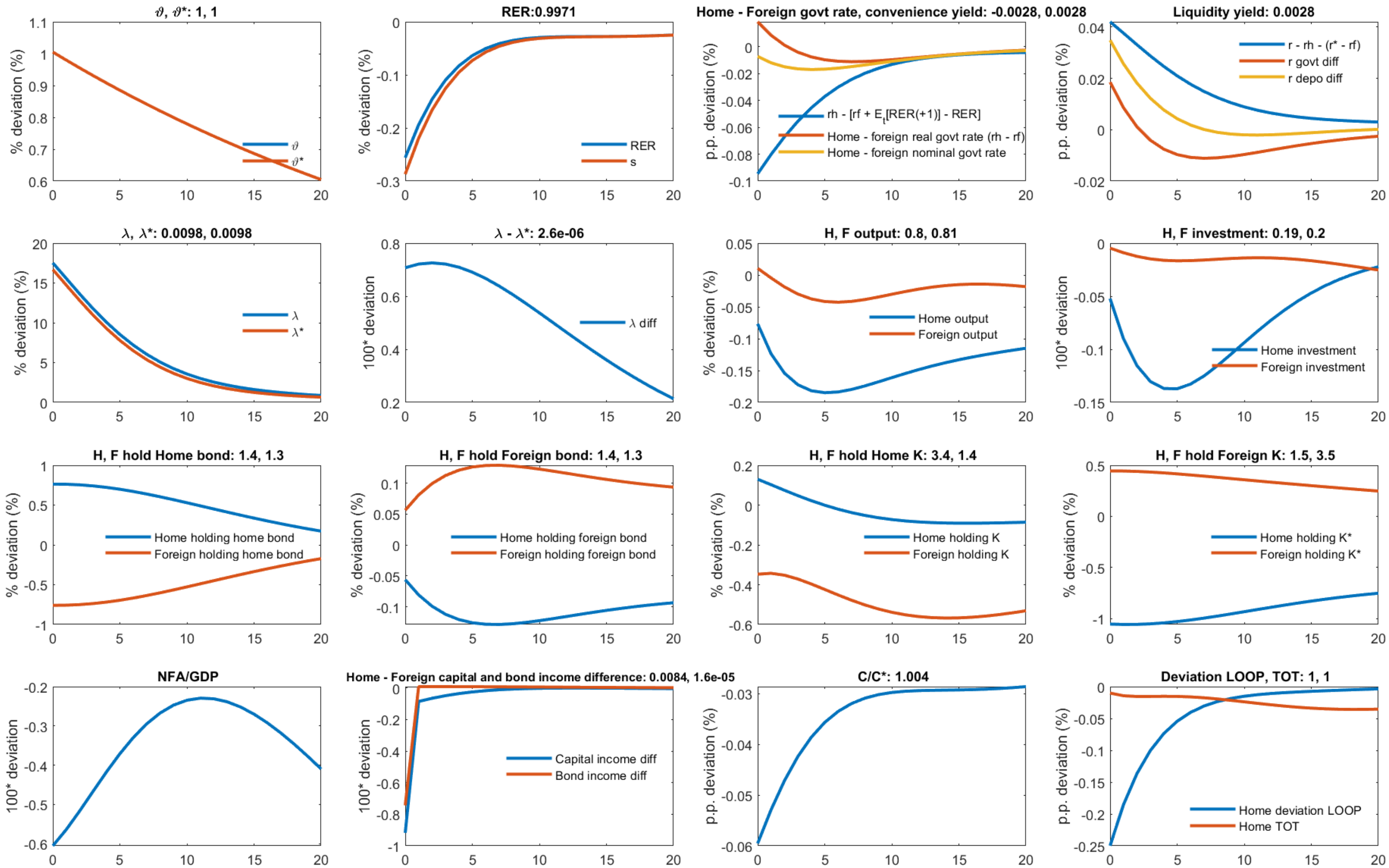
The special features of the US dollar and US financial assets in the world financial system has generated enormous academic interest over the last decade. The literature has established that the US benefits from an ”exorbitant privilege”, with US dollar denominated liabilities offering low returns to foreign investors in normal times, but on the flip side there is an “exorbitant duty” associated with a large US dollar appreciation during global crises, particularly global financial crises. We take a standard New Keynesian open economy model with balance sheet constrained banks and make a minimal additional assumption by letting US government assets have a higher collateral value than those of the rest of the world. We believe this is a highly realistic assumption. accurately characterizing the special liquidity features of US Treasuries in the global financial system. In steady state, this model captures the "exorbitant privilege", in that returns on US treasuries are below those of foreign governments, the US is a net debtor, but has a negative trade balance due to a excess income flows on its foreign assets relative to liabilities. In response to a global financial shock coming from a sudden tightening of balance sheet constraints for all banks, we show that the model accurately captures the empirical observations discussed in the introduction. Notably, the US dollar appreciates strongly, and the appreciation is associated with a spike in the convenience yield on US Treasuries relative to foreign government assets. Moreover, this appreciation is achieved even though US households have a diminished share of world wealth, as the appreciation of the US dollar imposes the "exorbitant duty" on the US. In addition, although the US government bond represents better collateral and a global financial crisis leads to an increase in demand for the 'safe asset', in equilibrium we see an external retrenchment in capital flows, as in the data. The model implies separate roles and transmission mechanisms for US monetary policy and liquidity provision, which have implications for understanding international spillovers of policies. We show that these results are robust to alternative calibrations of the model, and most results carry over to a case where a global downturn is precipitated by a uniform negative shock to all country's productivity. Due to the minimal assumptions required to endogenize the convenience yield and rationalize the specialness of the US, the framework presented can be readily extended for further analysis, including optimal policy considerations and implications for asset pricing.

Figure 2: Baseline with 1% global financial shock (ϑ, ϑ^*)



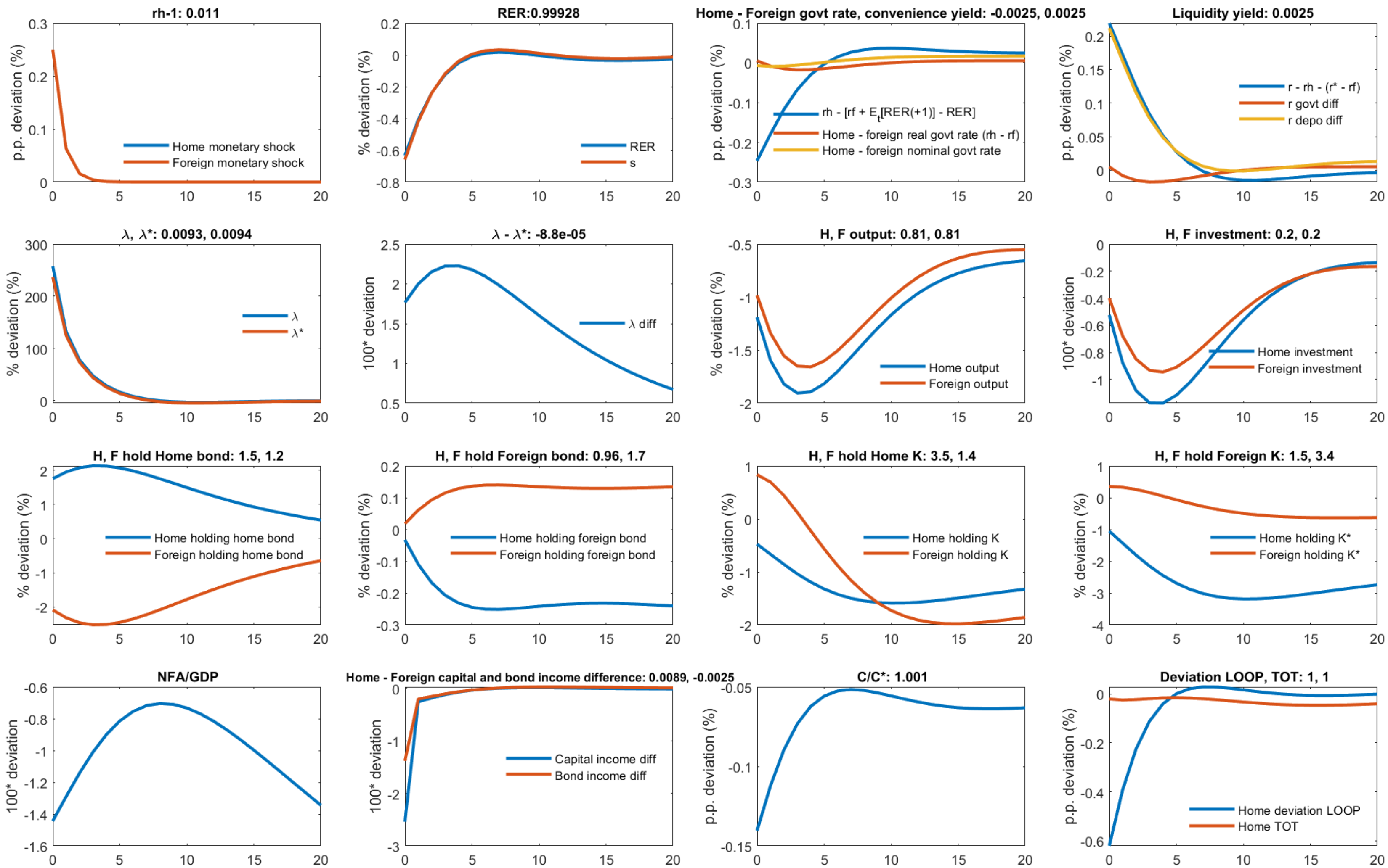
Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 3: 1% global financial shock (ϑ, ϑ^*) with $\kappa_{h1} = \kappa_{h1}^* = 0.05 < \kappa_{f1} = \kappa_{f1}^* = 0.401$



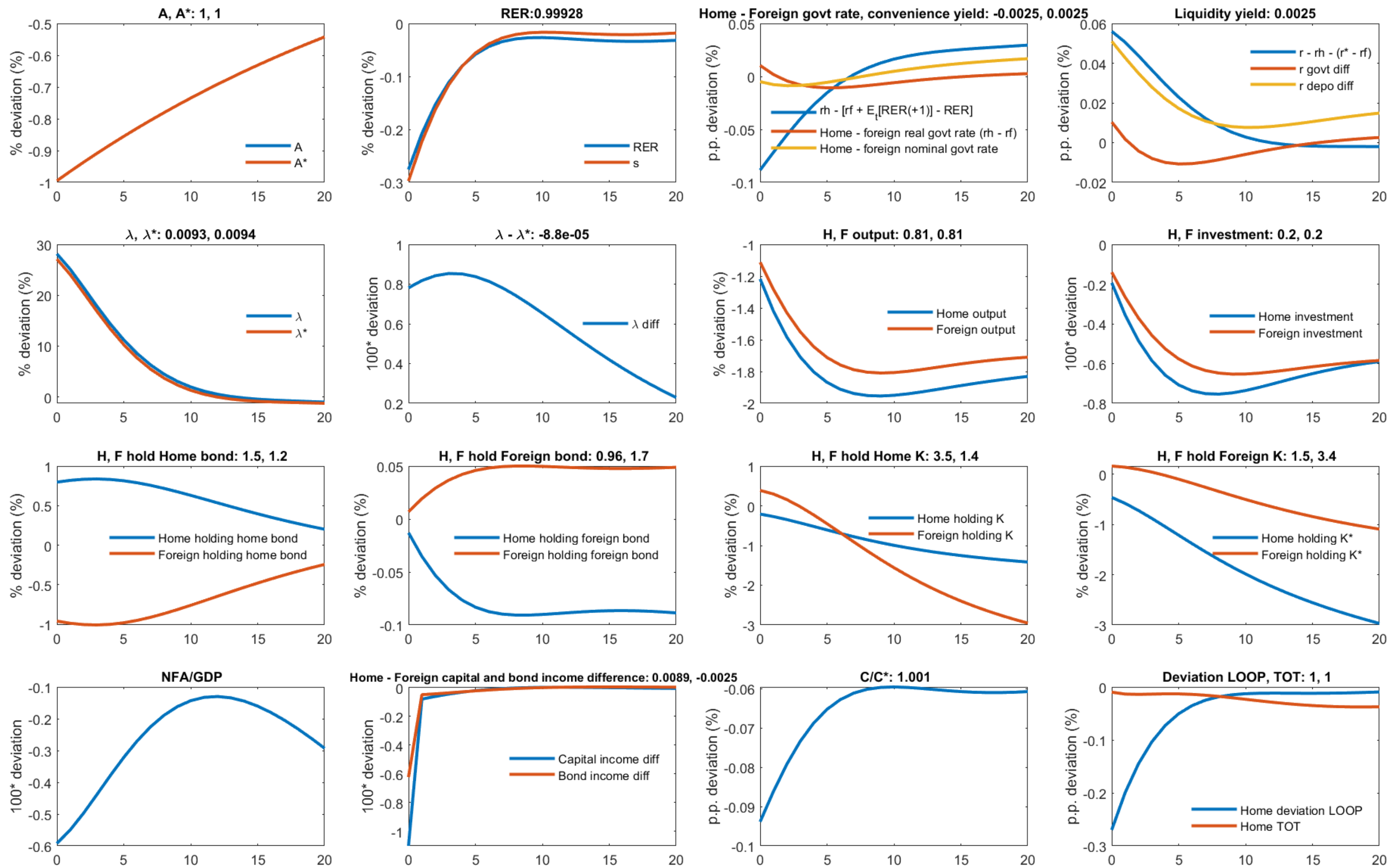
Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 4: 25 basis point both Home and Foreign monetary shock with baseline calibration



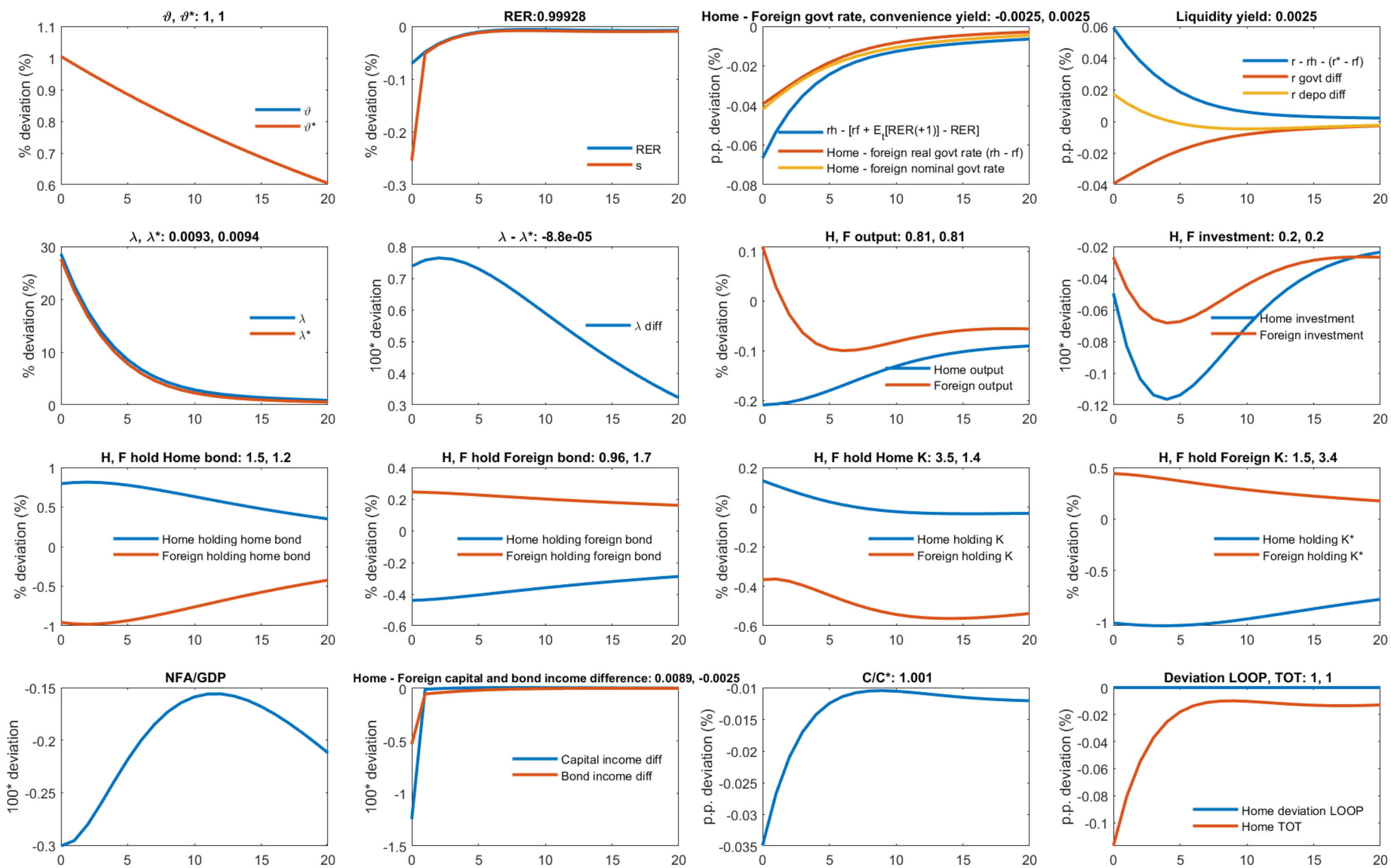
Notes: The figure shows IRF of a 0.25% global monetary shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 5: 1% TFP shock (A, A^*) with baseline calibration



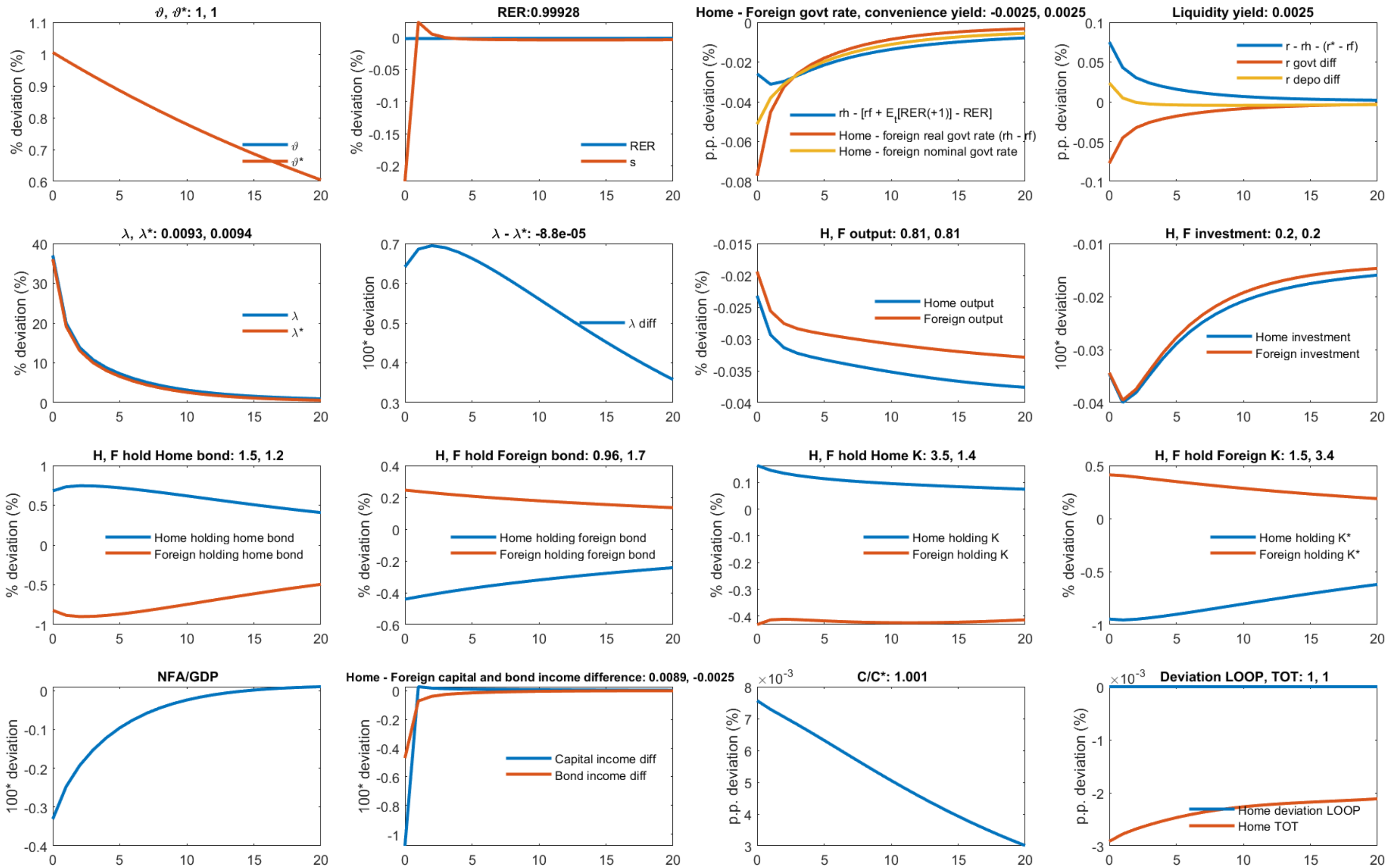
Notes: The figure shows IRF of a 1% global productivity shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 6: 1% global financial shock (ϑ, ϑ^*) with baseline calibration in PCP case



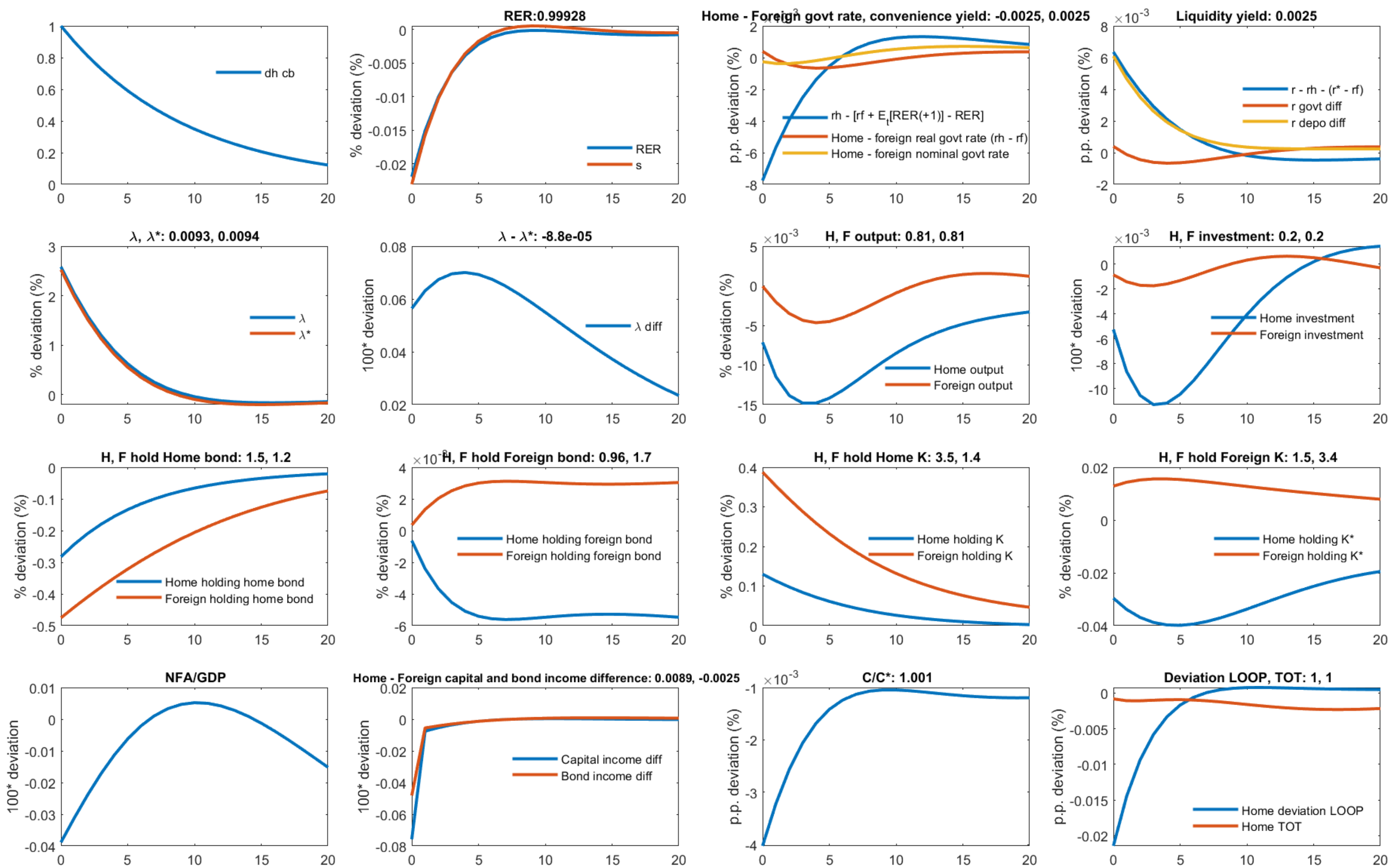
Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 7: 1% global financial shock (ϑ, ϑ^*) with baseline calibration in flexible price case



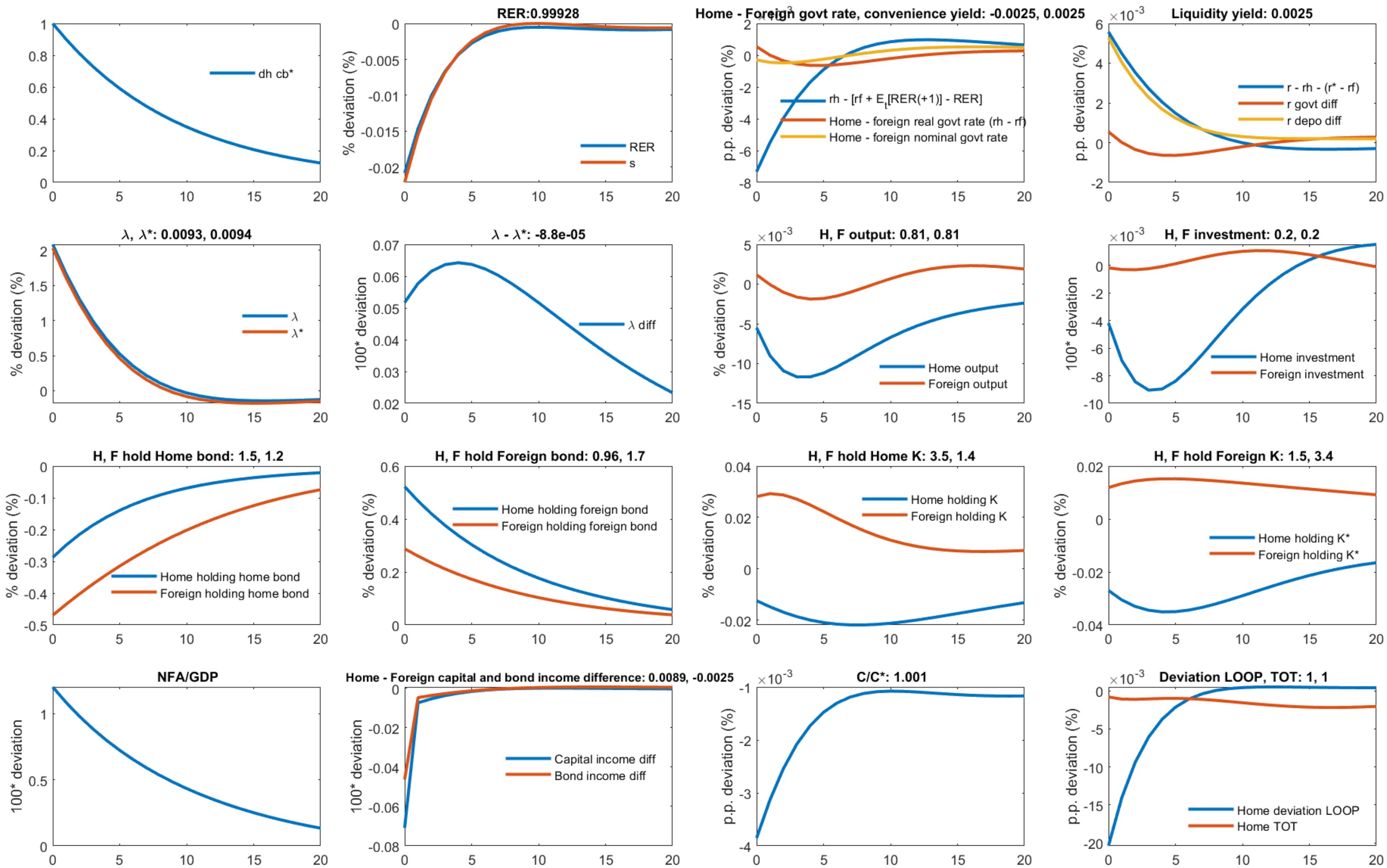
Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 8: 1% QT shock with purchase of Home bonds and sales of Home capital by Home central bank



Notes: The figure shows IRF of a 1% QT shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 9: 1% FXI shock with purchase of Home bonds and sales of Foreign bonds by Foreign central bank



Notes: The figure shows IRF of a 1% QT shock. Subtitles of the figure report the steady state value of the reporting variables.

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Online Appendix (not for publication)

A Collecting all the equations and rewriting the system in real terms

Define real debt holdings: $d_{h,t}=\frac{D_{h,t}}{P_t}$, $d_{f,t}=\frac{D_{f,t}}{P_t^*}$,

Terms of Trade: $\mathscr{S}_t=\frac{P_{f,t}}{P_{h,t}}$, $\mathscr{S}_t^*=\frac{P_{f,t}^*}{P_{h,t}^*}$,

Deviations from LOOP: $\mathscr{D}_t=\frac{S_tP_{h,t}^*}{P_{h,t}}$ $\mathscr{D}_t^*=\frac{S_tP_{f,t}^*}{P_{f,t}}$

Real Returns: $r_{h,t}=\frac{R_{h,t}P_{t-1}}{P_t}$, $r_{f,t}=\frac{R_{f,t}P_{t-1}^*}{P_t^*}$

Real marginal product of capital: $r_{K,t}=\frac{R_{K,t}}{P_t}$, $r_{K,t}^*=\frac{R_{K,t}^*}{P_t^*}$

Real net worth $n_t=\frac{N_t}{P_t}$, $n_t^*=\frac{N_t^*}{P_t^*}$

Real equity prices: $q_t=\frac{Q_t}{P_t},q_t^*=\frac{Q_t^*}{P_t^*}$

Real marginal costs: $mc_t=\frac{MC_t}{P_{h,t}}$, $mc_t^*=\frac{MC_t^*}{P_{f,t}^*}$

Price indices: $P(1,\mathscr{S}_t)=\frac{P_t}{P_{h,t}}$, $P^*(1,\mathscr{S}_t^*)=\frac{P_t^*}{P_{h,t}^*}$

PPI inflation rates: $\pi_{h,t}=\frac{P_{h,t}}{P_{h,t-1}}$, $\pi_{h,t}^*=\frac{P_{h,t}^*}{P_{h,t-1}^*}$ $\pi_{f,t}=\frac{P_{f,t}}{P_{f,t-1}}$, $\pi_{f,t}^*=\frac{P_{f,t}^*}{P_{f,t-1}^*}$

Also impose bond market clearing: $d_{h,t}^*=\bar{d}_h-d_{h,t}$, $d_{f,t}=\bar{d}_f-d_{f,t}^*$

labor market clearing: $L_t=H_t$, $L_t^*=H_t^*$

Real wage $w_t=\frac{W_t}{P_t}$, $w_t^*=\frac{W_t^*}{P_t^*}$

Real deposit (policy) rate $r_{t+1}=\frac{R_{t+1}P_t}{P_{t+1}}$ $r_{t+1}^*=\frac{R_{t+1}^*P_t^*}{P_{t+1}^*}$

Real exchange rate is implied by $RER_t=\frac{S_tP_t^*}{P_t}=\frac{\mathscr{D}_tP^*(1,\mathscr{S}_t^*)}{P(1,\mathscr{S}_t)}$. That is, the real exchange rate depends on both deviations from LOOP as well as movements in the terms of trade. Also, set $\bar{\pi}=0$

Balance of payments:

$$\begin{aligned}(C_t+I_t+I_t\phi(\tfrac{I_t}{I_{t-1}}))+d_{h,t}-\bar{d}_h+RER_td_{f,t}+q_t(K_{h,t}-K_t)+RER_tq_t^*K_{f,t}\\=\tfrac{Y_{h,t}}{P(1,\mathscr{S}_t)}(1-\xi(\pi_{h,t}))+\tfrac{\mathscr{D}_t}{P(1,\mathscr{S}_t)}Y_{h,t}^*(1-\xi(\pi_{h,t}^*))\\+r_{h,t}(d_{h,t-1}-\bar{d}_h)+RER_tr_{f,t}d_{f,t-1}+\tilde{r}_{k,t+1}(K_{h,t}-K_t)+RER_t\tilde{r}_{k,t+1}^*K_{f,t}\end{aligned}\tag{44}$$

Home Richardian household Euler equation:

$$1=E_t\beta r_{t+1}(\frac{C_{t+1}^R}{C_t^R})^{-\sigma}\equiv E_t\beta r_{t+1}\tilde{\Omega}_{t+1}\tag{45}$$

Foreign Richardian household Euler equation:

$$1 = E_t \beta r^*_{t+1} (\frac{C^{R*}_{t+1}}{C^{R*}_t})^{-\sigma} \equiv E_t \beta r^*_{t+1} \tilde{\Omega}^*_{t+1} \tag{46}$$

Home hand-to-mouth (Keynesian) household budget constraint:

$$C^K_t = w_t H^K_t \tag{47}$$

Foreign hand-to-mouth (Keynesian) household budget constraint:

$$C^{K*}_t = w^*_t H^{K*}_t \tag{48}$$

In aggregate, we have

$$C_t = (1-m) \times C^R_t + (m) \times C^K_t \tag{49}$$

$$H_t = (1-m) \times H^R_t + (m) \times H^K_t \tag{50}$$

Labor market clear implies

$$L_t = H_t$$

Profit max Home:

$$\begin{aligned} (1+s_t)Y_{h,t} - \varepsilon((1+s_t) - mc_t)Y_{h,t} \\ -\xi'(\pi_{h,t})\pi_{h,t}Y_{h,t} + E_t \beta \tilde{\Omega}_{t+1} \tfrac{P(1,\mathscr{S}_t)}{P(1,\mathscr{S}_{t+1})} \xi'(\pi_{h,t+1})\pi_{h,t+1}Y_{h,t+1} \quad &= 0 \end{aligned} \tag{51}$$

$$\begin{aligned} (1+s_t)Y^*_{h,t} - \varepsilon((1+s_t) - \tfrac{mc_t}{\mathscr{D}_t})Y^*_{h,t} \\ -\xi'(\pi^*_{h,t})\pi^*_{h,t}Y^*_{h,t} + E_t \beta \tilde{\Omega}_{t+1} \tfrac{P(1,\mathscr{S}_t)}{P(1,\mathscr{S}_{t+1})} \tfrac{\mathscr{D}_{t+1}}{\mathscr{D}_t} \xi'(\pi^*_{h,t+1})\pi^*_{h,t+1}Y^*_{h,t+1} \quad &= 0 \end{aligned} \tag{52}$$

Factor markets Home:

$$A_t(1-\alpha)(L^{1-\alpha}_t K^{\alpha}_t)mc_t = w_t P(1,\mathscr{S}_t)L_t \tag{53}$$

$$A_t \alpha (L^{1-\alpha}_t K^{\alpha}_t)mc_t = r_{K,t} P(1,\mathscr{S}_t)K_t \tag{54}$$

$$w_t = \chi C^{R\sigma}_t L^{R\psi}_t \tag{55}$$

$$w_t = \chi L_t^{K\psi} \tag{56}$$

Capital and Price of capital at Home:

$$K_{t+1} = I_t + (1-\delta)K_t \tag{57}$$

$$q_t = 1 + \psi'(\frac{I_t}{I_{t-1}})\frac{I_t}{I_{t-1}} + \psi(\frac{I_t}{I_{t-1}}) \tag{58}$$

$$Y_{h,t} + Y_{h,t}^* = A_t(L_t^\alpha K_t^{1-\alpha}) \tag{59}$$

Profit Max Foreign:

$$\begin{aligned} &(1+s_t^*)Y_{f,t}^* - \varepsilon((1+s_t) - mc_t^*)Y_{f,t}^* \\ -\xi'(\pi_{f,t}^*)\pi_{f,t}^* Y_{f,t}^* + E_t\beta\tilde{\Omega}_{t+1}^* \tfrac{\mathscr{S}_{t+1}^* P^*(1,\mathscr{S}_t^*)}{\mathscr{S}_t^* P^*(1,\mathscr{S}_{t+1}^*)}\xi'(\pi_{f,t+1}^*)\pi_{f,t+1}^* Y_{f,t+1}^* \quad &= 0 \end{aligned} \tag{60}$$

$$\begin{aligned} &(1+s_t^*)Y_{f,t} - \varepsilon((1+s_t^*) - \mathscr{D}_t^* mc_t^*)Y_{f,t} \\ -\xi'(\pi_{f,t})\pi_{f,t} Y_{f,t} + E_t\beta\tilde{\Omega}_{t+1}^* \tfrac{\mathscr{D}_t^*}{\mathscr{D}_{t+1}^*}\tfrac{\mathscr{S}_{t+1}^* P^*(1,\mathscr{S}_t^*)}{\mathscr{S}_t^* P^*(1,\mathscr{S}_{t+1}^*)}\xi'(\pi_{f,t+1})\pi_{f,t+1} Y_{f,t+1} \quad &= 0 \end{aligned} \tag{61}$$

Foreign factor markets:

$$A_t^*(1-\alpha)(L_t^{*(1-\alpha)}K_t^{*\alpha})mc_t^* = \frac{P^*(1,\mathscr{S}_t^*)}{\mathscr{S}_t^*}w_t^* L_t^* \tag{62}$$

$$A_t^*\alpha(L_t^{*(1-\alpha)}K_t^{*\alpha})mc_t^* = K_t^*\frac{P^*(1,\mathscr{S}_t^*)}{\mathscr{S}_t^*}r_{K,t}^* \tag{63}$$

$$w_t^* = \chi C_t^{R*\sigma} L_t^{R*\psi} \tag{64}$$

$$w_t^* = \chi L_t^{K*\psi} \tag{65}$$

Labor market clear implies

$$L_t^* = H_t^*$$

Capital and Price of capital Foreign:

$$K_{t+1}^* = I_t^* + (1-\delta)K_t^* \tag{66}$$

$$q_t^* = (1+\psi'(\frac{I_t^*}{I_{t-1}^*})\frac{I_t}{I_{t-1}} + \psi(\frac{I_t^*}{I_{t-1}^*})) \tag{67}$$

$$Y_{f,t}^* + Y_{f,t} = A_t^*(L_t^{*\alpha} K_t^{*(1-\alpha)})) \tag{68}$$

Market Clearing:
Bond market clearing:

$$d_{h,t}^* + d_{h,t} = \bar{d}_{h,t},\ d_{f,t} + d_{f,t}^* = \bar{d}_{f,t}$$

Home good:

$$Y_{h,t}(1-\xi(\pi_{h,t})) = \omega\left(\frac{1}{P(1,\mathscr{S}_t)}\right)^{-\mu}(C_t + I_t + I_t\phi(\frac{I_t}{I_{t-1}})) \tag{69}$$

$$Y_{h,t}^*(1-\xi(\pi_{h,t}^*)) = \frac{(1-n)}{n}(1-\omega^*)\left(\frac{1}{P^*(1,\mathscr{S}_t^*)}\right)^{-\mu}(C_t^* + I_t^* + I_t^*\phi(\frac{I_t^*}{I_{t-1}^*})) \tag{70}$$

Foreign good:

$$Y_{f,t}(1-\xi(\pi_{f,t})) = \frac{n}{1-n}(1-\omega)\left(\frac{\mathscr{S}_t}{P(1,\mathscr{S}_t)}\right)^{-\mu}(C_t + I_t + I_t\phi(\frac{I_t}{I_{t-1}})) \tag{71}$$

$$Y_{f,t}^*(1-\xi(\pi_{f,t}^*)) = \omega^*\left(\frac{\mathscr{S}_t^*}{P^*(1,\mathscr{S}_t^*)}\right)^{-\mu}(C_t^* + I_t^* + I_t^*\phi(\frac{I_t^*}{I_{t-1}^*})) \tag{72}$$

Home Bank:

$$E_t\tilde{\Lambda}_{t+1}\left(\tilde{r}_{k,t+1} - r_{t+1}\right) = \lambda_t\vartheta_t(\kappa_{Kh1} + \kappa_{Kh2}\tilde{K}_{h,t}) \tag{73}$$

$$E_t\tilde{\Lambda}_{t+1}\left(\frac{RER_{t+1}}{RER_t}\tilde{r}_{k,t+1}^* - r_{t+1}\right) = \lambda_t\vartheta_t(\kappa_{Kf1} + \kappa_{Kf2}RER_t\tilde{K}_{f,t}) \tag{74}$$

$$E_t\tilde{\Lambda}_{t+1}\left(r_{h,t+1} - r_{t+1}\right) = \lambda_t\vartheta_t(\kappa_{h1} + \kappa_{h2}\tilde{d}_{h,t}) \tag{75}$$

$$E_t\tilde{\Lambda}_{t+1}\left(\frac{RER_{t+1}}{RER_t}r_{f,t+1} - r_{t+1}\right) = \lambda_t\vartheta_t(\kappa_{f1} + \kappa_{f2}RER_t\tilde{d}_{f,t}) \tag{76}$$

$$\tilde{\Lambda}_{t+1} = \tilde{\Omega}_{t+1}\frac{\pi_{h,t+1}P(1,\mathscr{S}_{t+1})}{P(1,\mathscr{S}_t)}((1-\theta) + \theta\upsilon_{t+1})$$

$$\tilde{r}_{K,t+1} = \frac{r_{K,t+1} + (1-\delta)q_{t+1}}{q_t}$$

Home envelope condition:

$$\upsilon_t = \frac{E_t \tilde{\Omega}_{t+1} \frac{\pi_{h,t+1} P(1,\mathscr{S}_{t+1})}{P(1,\mathscr{S}_t)} \left((1-\theta)+\theta\upsilon_{t+1}\right) r_{t+1}}{1-\eta_t} \tag{77}$$

Home participation constraint:

$$\begin{aligned} \upsilon_t n_t &= \vartheta_t((\kappa_{Kh1}+\kappa_{Kh2} q_t K_{h,t+1}) q_t K_{h,t+1} + (\kappa_{Kf1}+\kappa_{Kf2} RER_t q_t^* K_{f,t+1}) RER_t q_t^* K_{f,t+1} \\ &\quad +(\kappa_{h1}+\kappa_{h2} d_{h,t}) d_{h,t} + (\kappa_{f1}+\kappa_{f2} RER_t d_{f,t}) RER_t d_{f,t}) \end{aligned} \tag{78}$$

Home net worth dynamics:

$$\begin{aligned} n_{t+1} = \quad & \theta((\tilde{r}_{k,t+1} - r_{t+1}) q_t K_{h,t+1} \\ & +(r_{h,t+1} - r_{t+1}) d_{h,t} \\ & +(\tfrac{RER_{t+1}}{RER_t} \tilde{r}_{kf,t+1} - r_{t+1}) RER_t K_{f,t+1} \\ & +(\tfrac{RER_{t+1}}{RER_t} r_{f,t+1} - r_{t+1}) RER_t d_{f,t} + r_{t+1} n_t) \\ & +\varphi \tfrac{P(1,\mathscr{S}_t)}{\pi_{h,t+1} P(1,\mathscr{S}_{t+1})} \left(q_t K_{t+1} + d_{h,t} + \tfrac{\mathscr{D}_t P(1,\mathscr{S}_t^*)}{P(1,\mathscr{S}_t)} d_{f,t} \right) \end{aligned} \tag{79}$$

Foreign Bank:

$$E_t \tilde{\Lambda}^*_{t+1} \left(\frac{RER_t}{RER_{t+1}} \tilde{r}_{k,t+1} - r^*_{t+1} \right) = \lambda_t^* \vartheta_t^* (\kappa^*_{Kh1} + \kappa^*_{Kh2} \tilde{K}^*_{ht} / RER_t) \tag{80}$$

$$E_t \tilde{\Lambda}^*_{t+1} \left(\tilde{r}^*_{k,t+1} - r^*_{t+1} \right) = \lambda_t^* \vartheta_t^* (\kappa^*_{Kf1} + \kappa^*_{Kf2} \tilde{K}^*_{ft}) \tag{81}$$

$$E_t \tilde{\Lambda}^*_{t+1} \left(\frac{RER_t}{RER_{t+1}} r_{h,t+1} - r^*_{t+1} \right) = \lambda_t^* \vartheta_t^* (\kappa^*_{h1} + \kappa^*_{h2} \tilde{d}^*_{h,t} / RER_t) \tag{82}$$

$$E_t \tilde{\Lambda}^*_{t+1} \left(r_{f,t+1} - r^*_{t+1} \right) = \lambda_t^* \vartheta_t^* (\kappa^*_{f1} + \kappa^*_{f2} \tilde{d}^*_{f,t}) \tag{83}$$

$$\tilde{\Lambda}^*_{t+1} = \tilde{\Omega}^*_{t+1} \pi^*_{h,t+1} \frac{P(1,\mathscr{S}^*_{t+1})}{P(1,\mathscr{S}^*_t)} \left((1-\theta)+\theta\upsilon^*_{t+1}\right)$$

$$\tilde{r}^*_{K,t+1} = \frac{r^*_{K,t+1} + (1-\delta) q^*_{t+1}}{q^*_t}$$

Foreign envelope condition:

$$\upsilon_t^* = \frac{E_t \Omega^*_{t+1} \pi^*_{h,t+1} \frac{P(1,\mathscr{S}^*_{t+1})}{P(1,\mathscr{S}^*_t)} \left((1-\theta)+\theta\upsilon^*_{t+1}\right) r^*_{t+1}}{1-\eta_t^*} \tag{84}$$

Foreign participation constraint:

$$\upsilon_t^* n_t^* = \vartheta_t^*((\kappa_{Kf1,t}^* + \kappa_{Kf2,t}^* q_t^* K_{ft+1}^*) q_t^* K_{ft+1}^* + (\kappa_{Kh1,t}^* + \kappa_{Kh2,t}^* \tfrac{1}{RER_t} q_t K_{h,t+1}^*) \tfrac{1}{RER_t} q_t K_{h,t+1}^* + (\kappa_{h1,t}^* + \kappa_{h2,t}^* \tfrac{1}{RER_t} d_{h,t}^*) \tfrac{1}{RER_t} d_{h,t}^* + (\kappa_{f1,t}^* + \kappa_{f2,t}^* d_{f,t}^*) d_{f,t}^*) \tag{85}$$

Foreign net worth dynamics:

$$\begin{aligned} n_{t+1}^* = & \theta((\tilde{r}_{k,t+1}^* - r_{t+1}^*) q_t^* K_{t+1} \\ & + (\tfrac{RER_t}{RER_{t+1}} (\tilde{r}_{k,t+1} - r_{t+1}^*) \tfrac{1}{RER_t} K_{h,t+1}^* \\ & + (\tfrac{RER_t}{RER_{t+1}} r_{h,t+1} - r_{t+1}^*) \tfrac{1}{RER_t} d_{h,t}^* \\ & + (r_{f,t+1} - r_{t+1}^*) d_{f,t}^* + r_{t+1}^* n_t^*) \\ & + \varphi \tfrac{P(1,\mathscr{S}_t^*)}{\pi_{h,t+1}^* P(1,\mathscr{S}_{t+1}^*)} \left(q_t^* K_{t+1}^* + \tfrac{P(1,\mathscr{S}_t)}{\mathscr{D}_t P(1,\mathscr{S}_t^*)} d_{h,t}^* + d_{f,t}^* \right) \end{aligned} \tag{86}$$

Home monetary Rule:

$$r_{h,t+1} = r_{h,ss} \left(\frac{P(1,\mathscr{S}_t)\pi_{h,t}}{P(1,\mathscr{S}_{t-1})} \right)^{\eta^\pi (1-\rho^R)} (r_{h,t})^{\rho^R} M_t \tag{87}$$

Foreign monetary Rule:

$$r_{f,t+1} = r_{f,ss} \left(\frac{\mathscr{S}_{t-1}^* P^*(1,\mathscr{S}_t^*)\pi_{f,t}^*}{\mathscr{S}_t^* P^*(1,\mathscr{S}_{t-1}^*)} \right)^{\eta^\pi (1-\rho^R)} (r_{f,t})^{\rho^R} M_t^* \tag{88}$$

Definitions:

$$\pi_{h,t} = \pi_{f,t} \frac{\mathscr{S}_{t-1}}{\mathscr{S}_t} \tag{89}$$

$$\pi_{f,t}^* = \pi_{h,t}^* \frac{\mathscr{S}_t^*}{\mathscr{S}_{t-1}^*} \tag{90}$$

$$\mathscr{D}_t = \mathscr{D}_t^* \frac{\mathscr{S}_t}{\mathscr{S}_t^*} \tag{91}$$

Equations (44) - (91}) give 46 equations in

$$C_t^K, C_t^{K*}, C_t^R, C_t^{R*}, L_t^K, L_t^{K*}, L_t^R, L_t^{R*}, I_t, I_t^*, K_{h,t}, K_{h,t}^*, K_{f,t}, K_{f,t}^*$$

$$\pi_{h,t}, \pi_{h,t}^*, \pi_{f,t}, \pi_{f,t}^*, w_t, w_t^*, q_t, q_t^*, mc_t, mc_t^*$$

$$r_{K,t}, r^*_{K,t}, r_t, r^*_t, r_{h,t}, r_{f,t}, Y_{h,t}, Y^*_{h,t},$$

$$Y_{f,t}, Y^*_{f,t}, \upsilon_t, \upsilon^*_t, \eta_t, \eta^*_t,$$

$$d_{h,t}, d_{f,t}, \mathscr{S}_t, \mathscr{S}^*_t, \mathscr{D}_t, \mathscr{D}^*_t, n_t, n^*_t$$

Endogenous state variables:
$n_t, n^*_t, K_{h,t}, K_{f,t}, K^*_{h,t}, K^*_{f,t+}, d_{h,t}, d_{f,t}, \mathscr{S}_{t-1}, \mathscr{S}^*_{t-1}$

B Steady state equations

Define real debt holdings: $d_h,\ d_f$,

Terms of Trade: $\mathscr{S} = \mathscr{S}^*$,

Deviations from LOOP: $\mathscr{D} = 1\ \mathscr{D}^* = 1$

Real Returns: $r_h\ r_f$

Real equity prices: $q = 1, q^* = 1$

Real marginal product of capital: $r_K = R_K,\ r^*_K = R^*_K$

Real net worth $n,\ \ n^*$

Real marginal costs: $mc = mc^* = 1$ (Setting $A = A^* = 1$)

Price indices: $P(1,\mathscr{S}),\ P^*(1,\mathscr{S})$

PPI inflation rates: $\pi_h = 1,\ \pi^*_h = 1\ \pi_f = 1,\ \pi^*_f = 1$

Also impose bond market clearing: $d^*_h = \bar{d}_h - d_h,\ d_f = \bar{d}_f - d^*_f$

labor market clearing: $L = H,\ L^* = H^*$

Real wage $w,\ \ w^*$

Real deposit (policy) rate $r\ \ r^*$

Subsidy rate $s = \frac{1}{\varepsilon - 1}$

Define the steady state real exchange rate as $RER = \frac{P^*(1,\mathscr{S})}{P(1,\mathscr{S})}$. So it depends only on the terms of trade and home bias in consumption aggregators.

Balance of payments:

$$C + I + \delta K = \frac{Y_h + Y^*_h}{P(1,\mathscr{S})} + (r_h - 1)(d_h - \bar{d}_h) + RER(r_f - 1)d_f + (\tilde{r}_k - 1)(K_h - K) + RER(\tilde{r}^*_k - 1)K_f \tag{92}$$

Home Euler equation:

$$1 = \beta r \tag{93}$$

Foreign Euler equation:

$$1 = \beta r \tag{94}$$

Profit max Home:

$$1 = mc \tag{95}$$

$$1 = mc \tag{96}$$

Factor markets Home:

$$(1-\alpha)(L^{1-\alpha}K^{\alpha}) = \chi C^{\sigma} L^{1+\psi} P(1,\mathscr{S}) \tag{97}$$

$$\alpha(L^{1-\alpha}K^{\alpha}) = r_K P(1,\mathscr{S})K \tag{98}$$

Capital and Price of capital at Home:

$$K\delta = I \tag{99}$$

$$q = 1 \tag{100}$$

$$Y_h + Y_h^* = (L^{\alpha}K^{1-\alpha}) \tag{101}$$

Profit Max Foreign:

$$1 = mc^* \tag{102}$$

$$1 = mc^* \tag{103}$$

Foreign factor markets:

$$(1-\alpha)(L^{*(1-\alpha)}K^{*\alpha}) = \frac{P^*(1,\mathscr{S})}{\mathscr{S}} \chi C^{*\sigma} L^{*1+\psi} \tag{104}$$

$$\alpha(L^{*(1-\alpha)}K^{*\alpha})^{\zeta} X^{*(1-\zeta)} = \frac{P^*(1,\mathscr{S})}{\mathscr{S}} r_K^* \tag{105}$$

Capital and Price of capital Foreign:

$$K\delta^* = I^* \tag{106}$$

$$q^* = 1 \tag{107}$$

$$Y_f^* + Y_f = (L^{*\alpha} K^{*(1-\alpha})) \tag{108}$$

Market Clearing:
Home good:

$$Y_h + Y_f = \omega \left(\frac{1}{P(1, \mathscr{S})} \right)^{-\mu} (C + \delta K) + \frac{(1-n)}{n} (1 - \omega^*) \left(\frac{1}{P^*(1, \mathscr{S})} \right)^{-\mu} (C^* + \delta K^*) \tag{109}$$

Foreign good:

$$Y_f + Y_f^* = \frac{n}{1-n} (1 - \omega) \left(\frac{\mathscr{S}}{P(1, \mathscr{S})} \right)^{-\mu} (C + \delta K) + \omega^* \left(\frac{\mathscr{S}}{P^*(1, \mathscr{S})} \right)^{-\mu} (C^* + \delta K) \tag{110}$$

Home Bank:

$$\tilde{\Lambda}(\tilde{r}_k - r) = \lambda \vartheta (\kappa_{Kh1} + \kappa_{Kh2} K_h) \tag{111}$$

$$\tilde{\Lambda}(\tilde{r}_k^* - r) = \lambda \vartheta (\kappa_{Kf1} + \kappa_{Kf2} K_f) \tag{112}$$

$$\tilde{\Lambda}(r_h - r) = \lambda \vartheta (\kappa_{h1} + \kappa_{h2} d_h) \tag{113}$$

$$\tilde{\Lambda}\left(r_f - r\right) = \lambda \vartheta (\kappa_{f1} + \kappa_{f2} d_f) \tag{114}$$

$$\tilde{\Lambda} = \beta \left((1 - \theta) + \theta \upsilon \right) \tag{115}$$

$$\tilde{r}_K = r_K + (1 - \delta) \tag{116}$$

Home envelope condition:

$$\upsilon = \frac{((1 - \theta) + \theta \upsilon)}{1 - \eta} \tag{117}$$

Home participation constraint:

$$\begin{aligned} \upsilon n \quad = \quad & \vartheta((\kappa_{Kh1} + \kappa_{Kh2} K_h) K_h + (\kappa_{Kf1} + \kappa_{Kf2} RERK_f) RERq^* K_f \\ & + (\kappa_{h1} + \kappa_{h2} d_h) d_h + (\kappa_{f1} + \kappa_{f2} RER_t d_f) RER_t d_f) \end{aligned} \tag{118}$$

Home net worth dynamics:

$$
\begin{aligned} n = \quad & \theta((\tilde{r}_k - r)K + (r_h - r)d_h + (r_f - r)\mathcal{Q}d_f + rn) \\ & +\varphi\left(K + d_h + \mathcal{Q}d_f\right) \end{aligned} \tag{119}
$$

Foreign Bank:

$$
\tilde{\Lambda}^*\left(\tilde{r}_k - r^*\right) = \lambda^* \vartheta^* (\kappa^*_{Kh1} + \kappa^*_{Kh1} K^*_h) \tag{120}
$$

$$
\tilde{\Lambda}^*\left(\tilde{r}^*_k - r^*\right) = \lambda^* \vartheta^* (\kappa^*_{Kf1} + \kappa^*_{Kf1} K^*_f) \tag{121}
$$

$$
\tilde{\Lambda}^*\left(r_h - r^*\right) = \lambda^* \vartheta^* (\kappa^*_{h1} + \kappa^*_{h2} d^*_h) \tag{122}
$$

$$
\tilde{\Lambda}^*\left(r_f - r^*\right) = \lambda^* \vartheta^* (\kappa^*_{f1} + \kappa^*_{f2} d^*_f) \tag{123}
$$

$$
\tilde{\Lambda}^* = \beta\left((1-\theta) + \theta \upsilon^*\right) \tag{124}
$$

$$
\tilde{r}^*_K = r^*_K + (1-\delta) \tag{125}
$$

Foreign envelope condition:

$$
\upsilon^* = \frac{((1-\theta) + \theta\upsilon^*)}{1-\eta^*} \tag{126}
$$

Foreign participation constraint:

$$
\begin{aligned} \upsilon^* n^* \quad = \quad & \vartheta^*((\kappa^*_{Kf1} + \kappa^*_{Kf2} K^*_f) K^*_f + (\kappa^*_{Kh1} + \kappa^*_{Kh2} \tfrac{1}{RER} K^*_h) \tfrac{1}{RER} K^*_h \\ & + (\kappa^*_{h1} + \kappa^*_{h2} \tfrac{1}{RER} d^*_{h,t}) \tfrac{1}{RER} d^*_h + (\kappa^*_{f1} + \kappa^*_{f2} d^*_f) d^*_f) \end{aligned} \tag{127}
$$

Foreign net worth dynamics:

$$
\begin{aligned} n^* = \quad & \theta((\tilde{r}^*_k - r^*)K^* + (r_h - r^*)\tfrac{d^*_h}{RER} + (r_f - r^*)d^*_f + r^* n^*) \\ & +\varphi\left(K^* + \tfrac{d^*_h}{RER} + d^*_f\right) \end{aligned} \tag{128}
$$

Home monetary policy

$$
r_h = r_{h,ss} \tag{129}
$$

Foreign monetary policy

$$
r_f = r_{f,ss} \tag{130}
$$

Take mc, r, q, I, $\tilde{\Lambda}$ as given (and same for Foreign). Then we have (92), (97), (98), (**??**), (101),(104), (105), (**??**), (108), (109), (110), (111), (113), (114), (117), (118), (119), (121), (122), (123), (126), (127), (128),

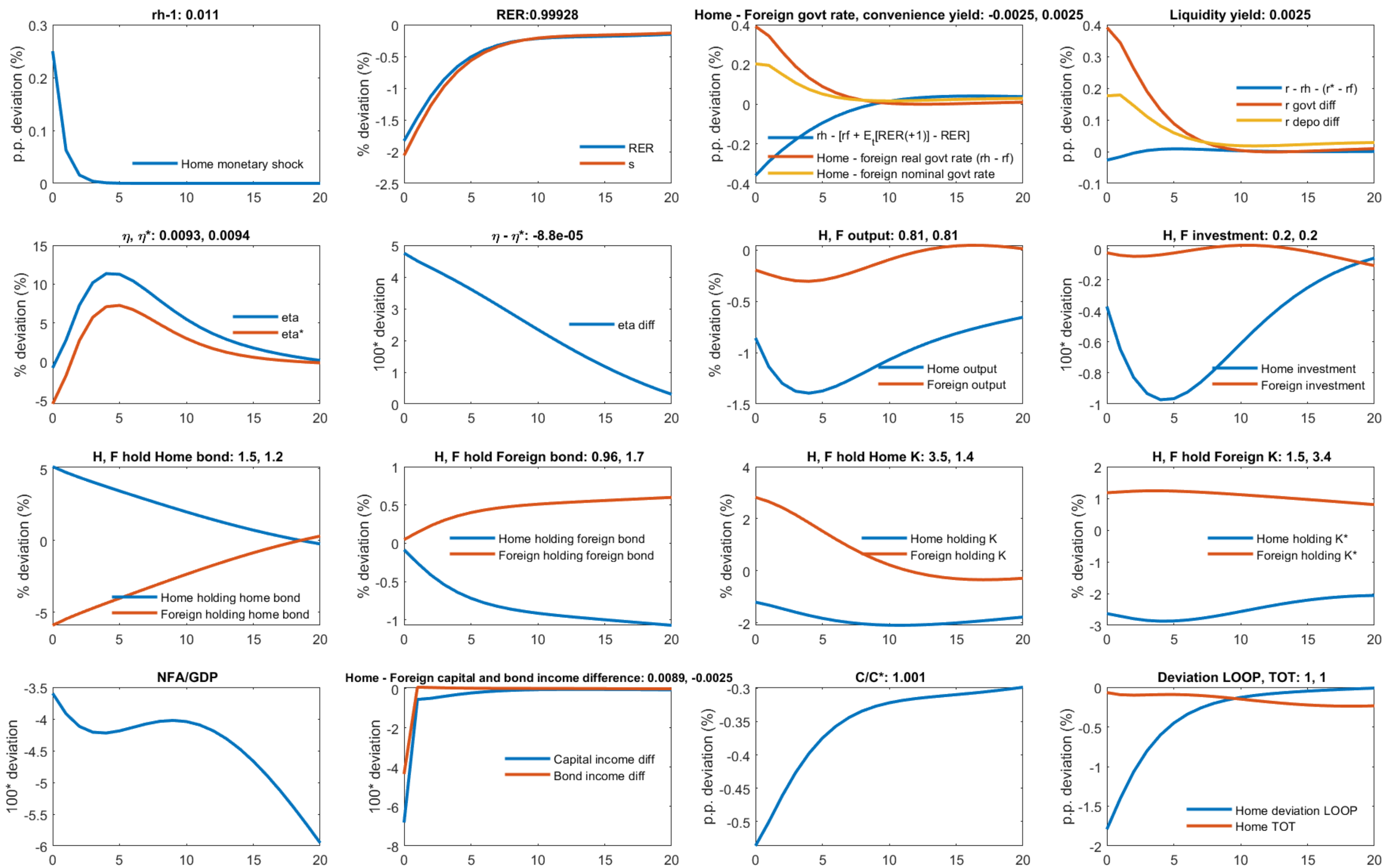
Solve for C, C^*, K, K^*,X, X^*, L, L^*, Y, Y^*
(Note just add $Y_h + Y_h^* = Y$ together)
$\mathscr{S}$, d_h, d_f, n, n^*,υ, υ^* η, η^*, r_k, r_k^*, r_h, r_f

C Additional IRF analysis

C.1 US Monetary Contraction

Figure 10 shows the response to a surprise monetary tightening in the US Rey (2015), Rey (2016), Kalemli-Özcan (2019), Curcuru et al. (2018),and Miranda-Agrippino and Rey (2020) have emphasized the importance of spillovers from US monetary policy in driving the business cycle and monetary policy choices of other countries. In this figure, we see the usual effects on the US of a monetary contraction - increased real interest rates, a drop in investment, consumption and output. The monetary contraction leads to an appreciation through the usual channel of tight money, but also there is an increase in the convenience yield on US Treasury bonds. As investment in capital becomes less attractive, US banks switch their demand toward domestic bonds, which lowers their expected return relative to Foreign bonds - that is, an increase in the liquidity yield on US bonds. We can also see that the gap between deposit rates and liquid bond rates in the US widens relative to that in the rest of the world. As in the case of the global financial shock, US NFA to GDP falls, and there is a net transfer to the rest of the world. The contraction in the US spills over to the Foreign country through conventional channels, but also through financial channels that are unconventional. As US banks demand switches from equities to US Treasury bonds, lowering the return on those bonds, they acquire US bonds from Foreign banks. There is a tightening of financial constraints in the Foreign country, which leads to a drop in investment demand there, and an increase in demand for local government bonds. However, the effects on the real economy are smaller in the Foreign country than in the US.

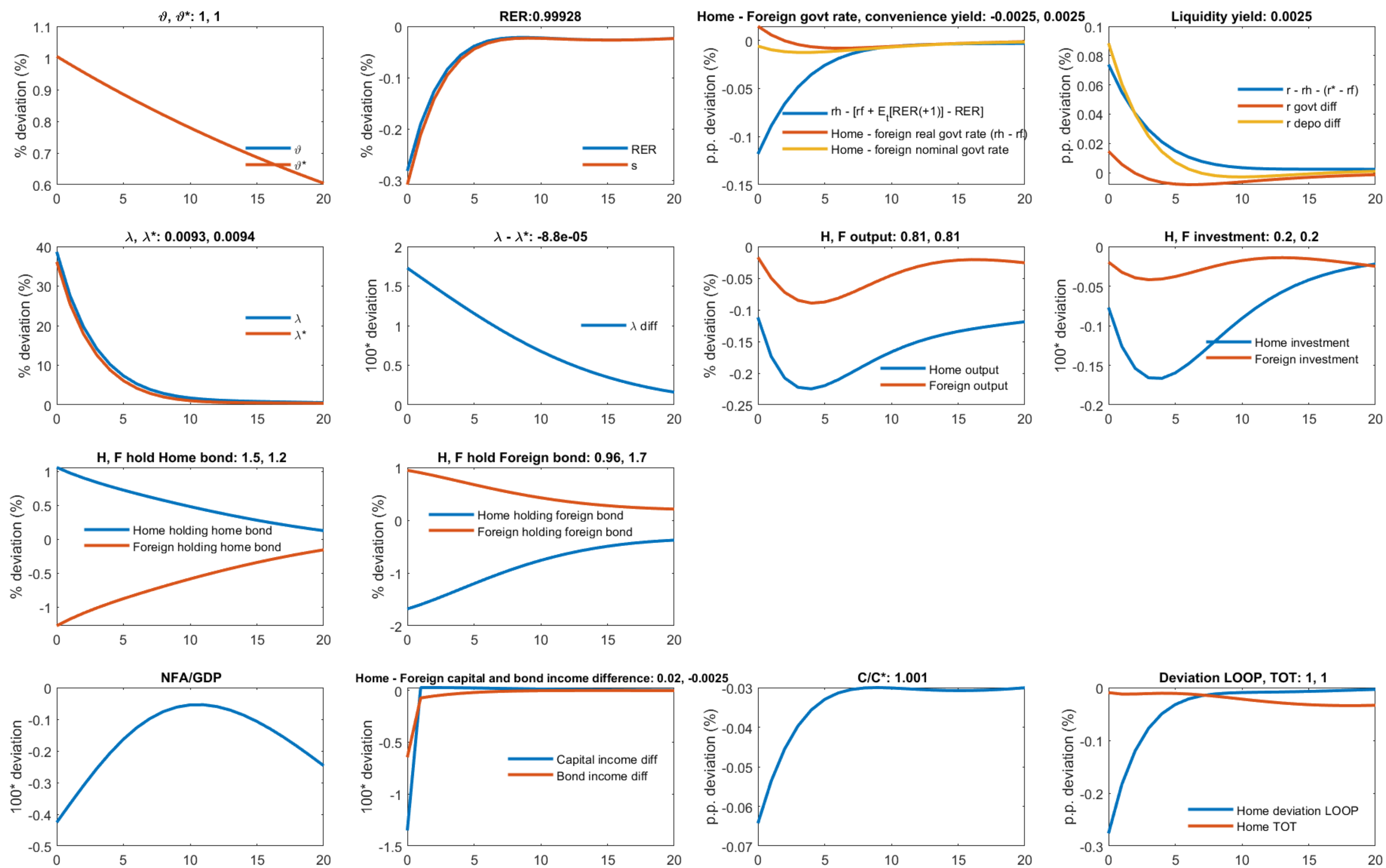
Figure 10: 25 basis point Home monetary shock with baseline calibration



Notes: The figure shows IRF of a 0.25% Home monetary shock. Subtitles of the figure report the steady state value of the reporting variables.

C.2 Baseline global financial shock without internatinal capital trade

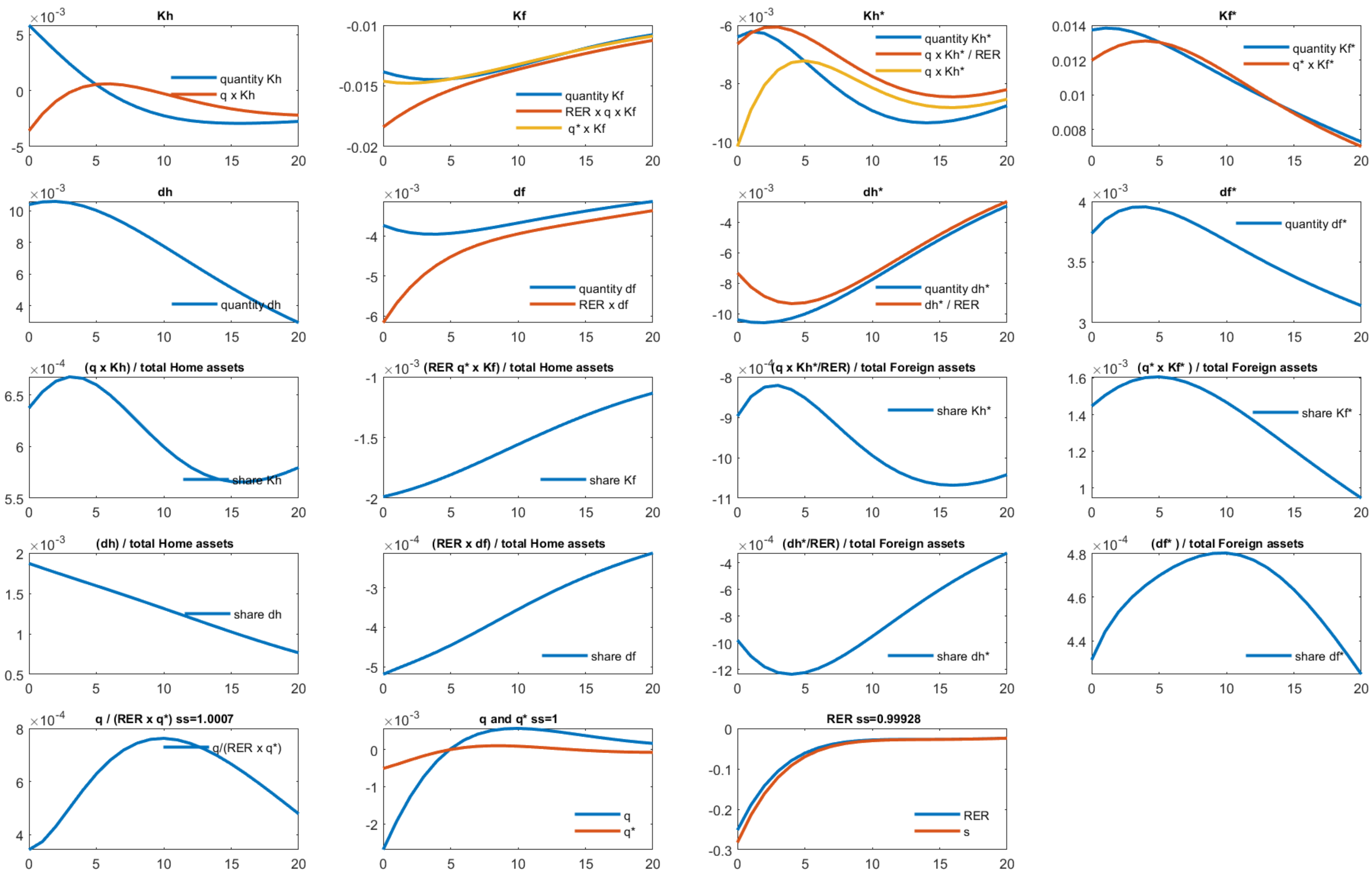
Figure 11: 1% global financial shock (ϑ, ϑ^*) with no capital trade



Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

C.3 Baseline global financial shock portfolio dynamics

Figure 12: Portfolio dynamics under baseline case with 1% global financial shock (ϑ, ϑ^*)

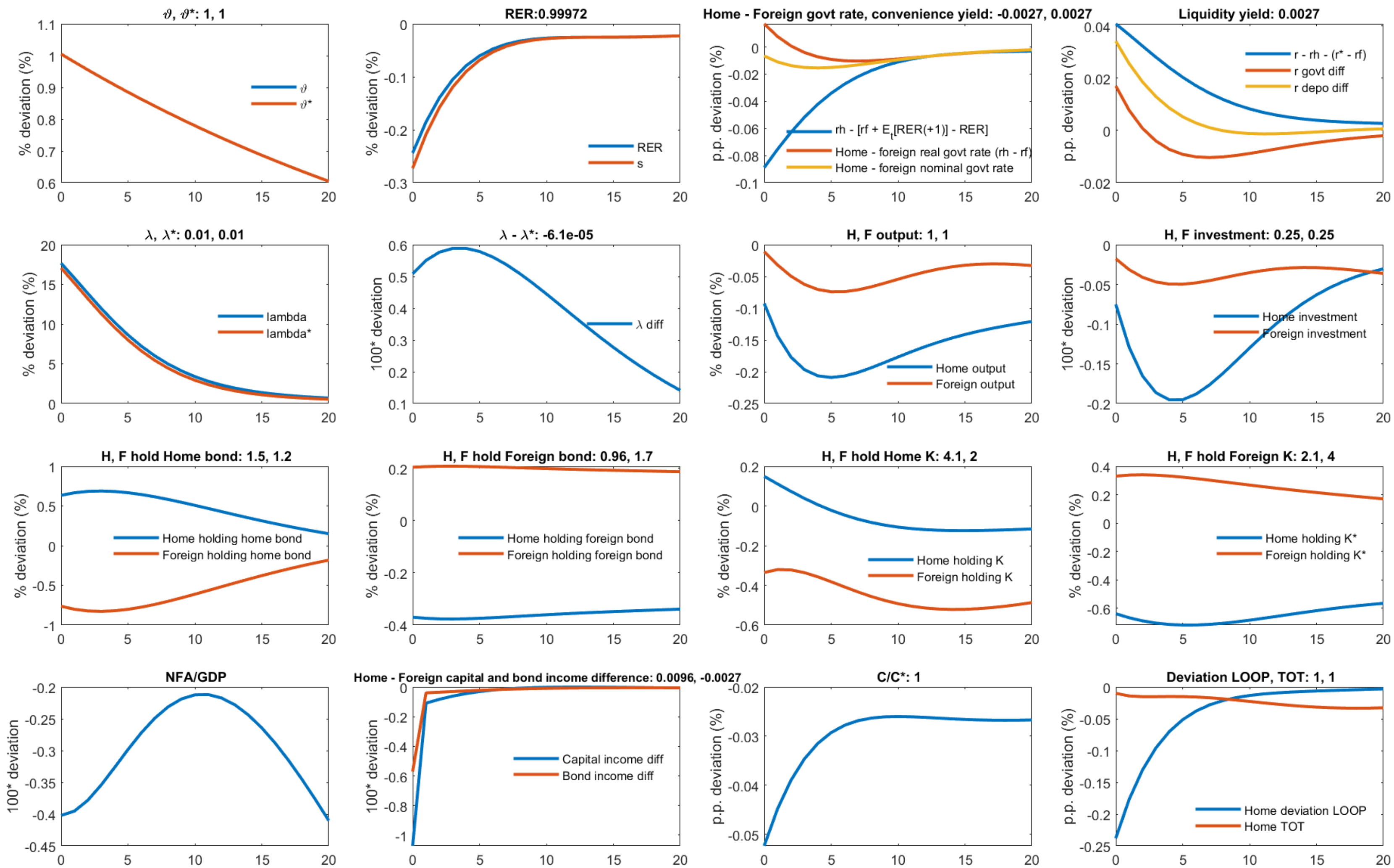


Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

C.4 IRF of global shocks without the Keynesian households

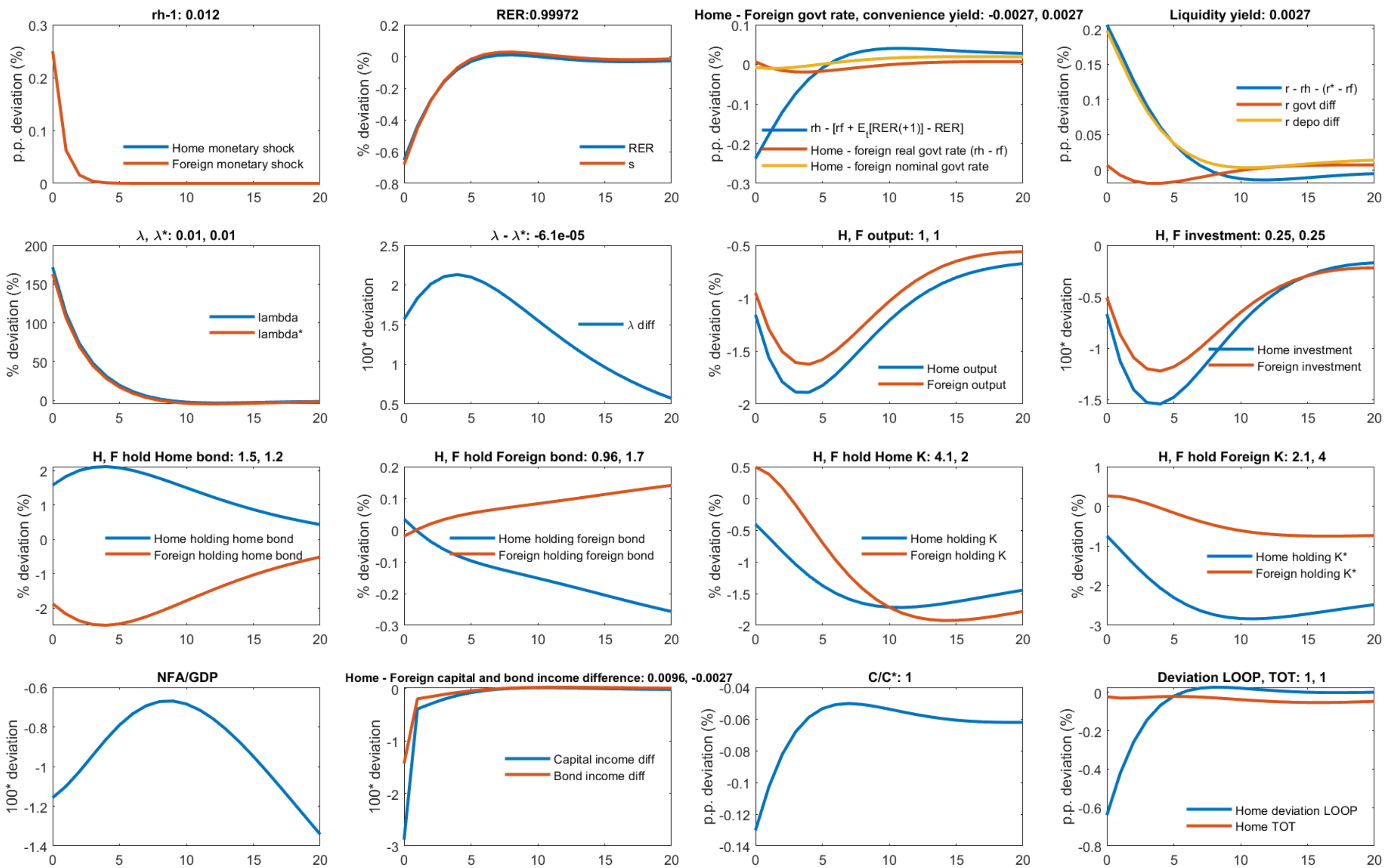
In the next three figures, we report the case of $m = 0$ with global financial shock, global monetary shock and global TFP shock. The figures are quantitatively similar to the baseline calibration, indicating hand-to-mouth households do not alter the IRF analysis.

Figure 13: 1% global financial shock (ϑ, ϑ^*) without Keynesian households



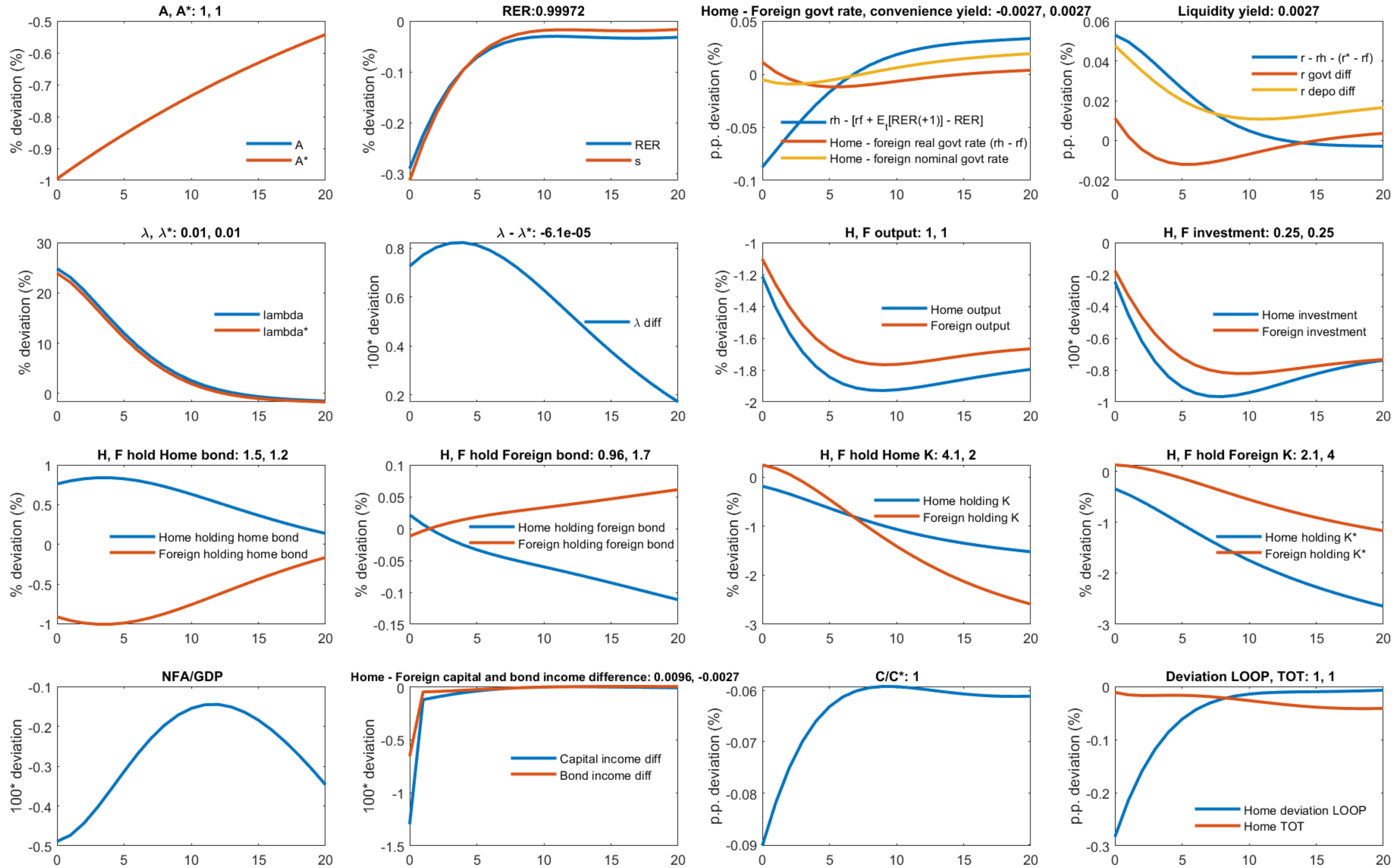
Notes: The figure shows IRF of a 1% global financial shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 14: 25 basis point both Home and Foreign monetary shock without Keynesian households



Notes: The figure shows IRF of a 0.25% global monetary shock. Subtitles of the figure report the steady state value of the reporting variables.

Figure 15: 1% TFP shock (A, A^*) without Keynesian households



Notes: The figure shows IRF of a 1% global productivity shock. Subtitles of the figure report the steady state value of the reporting variables.

D Unconditional moments with different assumptions

In this section, we report the unconditional moments in Table 4 with alternative assumptions. In particular, we assume 1) no convenience yield channel by assuming no collateral advantage, 2) PCP rather than LCP and 3) Both PCP and no convenience yield.

In each of the tables below, we report the original model implied unconditional moment in column (1). Column (2)-(4) reports the conditional and unconditional moments under alternative assumptions.

In Table 5, we assume there is no collateral advantage for the US Treasury. We assume $\kappa_{h1} = \kappa^*_{h1} = \kappa_{f1} = \kappa^*_{f1} = 0.025$ so all bonds are equally well to be served as collateral. The most obvious different from the original model is that the exchange rate becomes much less volatile. It is less volatile than output and consumption unconditionally. It is also less volatile in the high financial volatility state, which is at odd with the data. It also implies a positive Fama β.

Table 5: Long-run moments without convenience yield

		Model with no convenience yield		
	Original model moments unconditional	Model moments conditional on the low volatility state	Model moments unconditional	Model moments conditional on the high volatility state
	(1)	(2)	(3)	(4)
Exchange rates				
$\sigma(\Delta s)/\sigma(\Delta GDP)$	2.5	1.19	0.84	0.35
$\sigma(\Delta s)/\sigma(\Delta c)$	2.0	0.95	0.91	0.72
$\sigma(i-i^*)/\sigma(\Delta s)$	0.19	0.22	0.22	0.22
Fama β	-0.03	1.36	1.36	1.35
$\rho(\Delta q, \Delta c - \Delta c^*)$	0.16	-0.09	-0.09	-0.09
$\sigma(\Delta q)/\sigma(\Delta s)$	0.93	0.91	0.91	0.91
Persistence				
$\rho(\Delta s)$ (NER)	-0.09	-0.06	-0.06	-0.06
$\rho(q)$ (RER)	0.89	0.96	0.96	0.97
$\rho(i-i^*)$	0.95	0.93	0.95	0.98
$\rho(i)$	0.99	0.99	0.99	0.99
Trade balance				
$corr(\Delta nx, \Delta q)$	0.76	0.6	0.6	0.6
$\sigma(\Delta nx)/\sigma(\Delta q)$	0.27	0.45	0.45	0.45
Business cycle				
$\sigma(\Delta c)/\sigma(\Delta GDP)$	1.2	1.3	0.92	0.49
$\rho(\Delta c, \Delta GDP)$	0.78	0.80	0.71	0.72
$\rho(\Delta I, \Delta GDP)$	0.66	0.69	0.85	0.96
$\rho(\Delta GDP, \Delta GDP^*)$	0.56	0.78	0.88	0.98
$\rho(\Delta c, \Delta c^*)$	0.05	0.1	0.16	0.47
$\rho(\Delta I, \Delta I^*)$	0.54	0.89	0.97	0.99

Data moments are computed quarterly from 1999Q1 to 2023Q1. Model implied moments are performed with 15,000-quarter observations and burning the first 100 quarters.

In Table 6, we assume PCP so there is no deviation from LOOP ($D = D^* = 1$). The most obvious different from the original model is that the exchange rate becomes less volatile and also results in very volatile trade balance relative to real exchange rate.

Table 6: Long-run moments with PCP

		Model with PCP		
	Original model moments unconditional	Model moments conditional on the low volatility state	Model moments unconditional	Model moments conditional on the high volatility state
	(1)	(2)	(3)	(4)
Exchange rates				
$\sigma(\Delta s)/\sigma(\Delta GDP)$	2.5	1.27	1.62	1.88
$\sigma(\Delta s)/\sigma(\Delta c)$	2.0	1.22	2.24	6.07
$\sigma(i-i^*)/\sigma(\Delta s)$	0.19	0.23	0.22	0.22
Fama β	-0.03	-0.62	-1.49	-1.76
$\rho(\Delta q, \Delta c - \Delta c^*)$	0.16	-0.19	0.01	0.38
$\sigma(\Delta q)/\sigma(\Delta s)$	0.93	0.26	0.25	0.24
Persistence				
$\rho(\Delta s)$ (NER)	-0.09	-0.42	-0.44	-0.46
$\rho(q)$ (RER)	0.89	0.99	0.98	0.94
$\rho(i-i^*)$	0.95	0.92	0.85	0.82
$\rho(i)$	0.99	0.99	0.99	0.97
Trade balance				
$corr(\Delta nx, \Delta q)$	0.76	0.94	0.97	0.99
$\sigma(\Delta nx)/\sigma(\Delta q)$	0.27	1.92	1.71	1.62
Business cycle				
$\sigma(\Delta c)/\sigma(\Delta GDP)$	1.2	1.04	0.72	0.31
$\rho(\Delta c, \Delta GDP)$	0.78	0.64	0.42	0.05
$\rho(\Delta I, \Delta GDP)$	0.66	0.55	0.59	0.62
$\rho(\Delta GDP, \Delta GDP^*)$	0.56	-0.03	-0.52	-0.86
$\rho(\Delta c, \Delta c^*)$	0.05	0.06	0.07	0.15
$\rho(\Delta I, \Delta I^*)$	0.54	0.83	0.89	0.97

Data moments are computed quarterly from 1999Q1 to 2023Q1. Model implied moments are performed with 15,000-quarter observations and burning the first 100 quarters.

In Table 7, we assume there are PCP and no collateral advantage for the US Treasury. That is, we assume $\kappa_{h1} = \kappa^*_{h1} = \kappa_{f1} = \kappa^*_{f1} = 0.025$ so all bonds are equally well to be served as collateral and also there is no deviation from LOOP ($D = D^* = 1$). The model then retains the caveats from the two previous table. The exchange rate becomes much less volatile than output consumption and trade balance unconditionally. The exchange rate is less volatile in the high financial volatility state. It also implies a positive Fama β.

Table 7: Long-run moments with PCP and without convenience yield

		Model with PCP and no convenience yield		
	Original model moments unconditional	Model moments conditional on the low volatility state	Model moments unconditional	Model moments conditional on the high volatility state
	(1)	(2)	(3)	(4)
Exchange rates				
$\sigma(\Delta s)/\sigma(\Delta GDP)$	2.5	1.00	0.73	0.32
$\sigma(\Delta s)/\sigma(\Delta c)$	2.0	0.90	0.86	0.64
$\sigma(i-i^*)/\sigma(\Delta s)$	0.19	0.11	0.11	0.11
Fama β	-0.03	0.42	0.41	0.40
$\rho(\Delta q, \Delta c - \Delta c^*)$	0.16	-0.31	-0.31	-0.31
$\sigma(\Delta q)/\sigma(\Delta s)$	0.93	0.27	0.27	0.27
Persistence				
$\rho(\Delta s)$ (NER)	-0.09	-0.4	-0.4	-0.4
$\rho(q)$ (RER)	0.89	0.99	0.99	0.99
$\rho(i-i^*)$	0.95	0.99	0.99	0.99
$\rho(i)$	0.99	0.97	0.97	0.97
Trade balance				
$corr(\Delta nx, \Delta q)$	0.76	0.92	0.92	0.92
$\sigma(\Delta nx)/\sigma(\Delta q)$	0.27	2.1	2.1	2.1
Business cycle				
$\sigma(\Delta c)/\sigma(\Delta GDP)$	1.2	1.12	0.86	0.50
$\rho(\Delta c, \Delta GDP)$	0.78	0.69	0.66	0.73
$\rho(\Delta I, \Delta GDP)$	0.66	0.62	0.80	0.95
$\rho(\Delta GDP, \Delta GDP^*)$	0.56	0.39	0.67	0.94
$\rho(\Delta c, \Delta c^*)$	0.05	0.11	0.19	0.55
$\rho(\Delta I, \Delta I^*)$	0.54	0.96	0.99	0.99

Data moments are computed quarterly from 1999Q1 to 2023Q1. Model implied moments are performed with 15,000-quarter observations and burning the first 100 quarters.